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# Renewable Agriculture and Food Systems

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*Renewable Agriculture and Food Systems* provides an international forum for original research and review articles on the biological, physical, social science, and policy aspects of alternative agriculture and food systems, focusing on the effective use of renewable resources and biodiversity in agro-ecosystems. The journal particularly welcomes multidisciplinary, holistic, systems research that addresses the multiple challenge of economically meeting basic human needs for food, fiber, and energy while maintaining essential natural and environmental resources.


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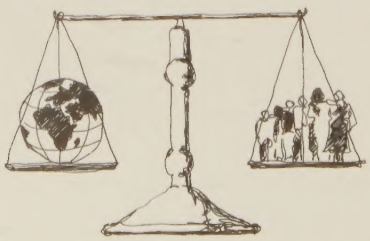

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CAB International
Wallingford
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UK
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*Fax:* +44(0)1491 829292
*E-mail:* cabi@cabi.org

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CABI Publishing North America
875 Massachusetts Avenue
7th Floor
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USA
*Tel:* +1 617 395 4056
*Fax:* +1 617 354 6875
*E-mail:* cabi-nao@cabi.org

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# Farmers' verification of improved land-use alternatives in the transitional *Badia* of Jordan

Feras M. Ziadat*, Butros I. Hattar, and Akram S. Baqain

Faculty of Agriculture, University of Jordan, Amman, Jordan.
*Corresponding author: fziadat@ju.edu.jo

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## Abstract

Decisions on land-use sustainability are particularly critical in fragile semi-arid regions of the world, especially those involving the social factor: people and communities. Typical of such an area is the Middle East region, especially Jordan which is beset by climatic constraints. New land-use alternatives were introduced by the Jordan Arid Zone Productivity Project (JAZPP) to improve land productivity in the arid to semi-arid (transitional *Badia*) land in Jordan. These alternatives were verified within experimental stations under controlled conditions. Dissemination of these findings would be successful if they suit the needs and resources of farmers. Therefore, verification of the success of these techniques under a wide range of biophysical and socio-economic conditions was necessary to judge their suitability to the target area. Various interventions were implemented on 14 sites that represent different biophysical and socio-economic conditions over the study area. With close monitoring and follow-up, successful and encouraging results were reported during the first season, even with lower rainfall than average, suggesting that these techniques were biophysically suitable for the target area. During the second season, maintenance and guarding were assigned to the farmers. Seven out of the 14 sites failed for various reasons: multiownership regime, reluctance of farmers to adopt new land use and insufficient protection and/or guarding measures. The study highlighted the importance of the farmers' comments and discussion of their specific problems and needs. This helped to improve these interventions to suit the farmers' requirements and may be important in facilitating widespread adoption and sustainability of these new land-use alternatives in the Jordanian *Badia* as well as in other areas of similar environment.

**Key words:** arid to semi-arid regions, land and water management, water harvesting, participatory approach, land ownership

## Introduction

The transitional *Badia* in Jordan represents areas located between arid and semi-arid regions (areas receiving 100–200 mm of annual rainfall). The arid and semi-arid areas represent about 26% of the global area of the Earth (about 38.25 million km$^2$)[1]. In addition to its importance as a natural resource asset in Jordan, the transitional *Badia* is considered as a buffer zone that plays a major role in protecting the productive land bordering this area toward the west from desertification threats. The inadequate amount and unfavorable distribution of precipitation, coupled with poor management and uncontrolled grazing practices, are resulting in poor vegetation cover and accelerated land degradation. The current management of land and water resources in that area is not sufficient to cope with these challenges. The Jordanian transitional *Badia* covers an area of 1,200,000 hectares, which constitutes 15% of the total area of Jordan (Fig. 1). It has a potential for development and represents a viable and strategic asset for the country[2–4]. The main characteristics of this area are low annual rainfall (100–200 mm) with uneven distribution and high intensity. Soils are highly susceptible to dispersion and capping[5]. Water infiltration is thus very low; therefore, low to moderate rainstorms can lead to considerable runoff. Coupled with very high evapotranspiration rates, this results in little moisture being available for plants. It has been estimated that if the runoff water is effectively used for supplementary irrigation, it would be sufficient for some 75,000 additional hectares of barley (*Hordeum marinum* L.), which would generate 370,000 tonnes of dry matter biomass. Thus, current production figures are far below satisfactory levels[2]. Various production techniques were introduced by the

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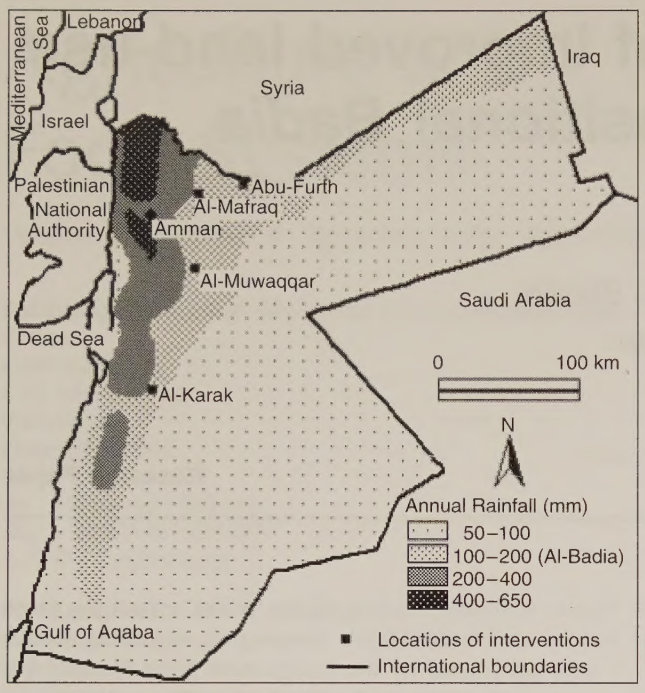


**Figure 1.** Locations of the intervention sites within the Jordanian transitional *Badia* region (100–200 mm rainfall).

Jordan Arid Zone Productivity Project (JAZPP) and implemented in controlled field trials at research stations[2], but were not tested in the farmers' fields. The aim of these interventions was to improve land productivity in the transitional *Badia*. However, it was necessary to verify these interventions with more emphasis on performance in farmers' fields. On-farm testing and validation of technologies developed under controlled conditions (on-station) were recommended in order to identify any constraints to adoption[6].

The study area is dominated by stony and rocky land (39%) and rangeland (33%). Rainfed agriculture, mainly barley cultivation, occupies 23%, urban and associated land occupies 2%, and irrigated agriculture (from pumped well-water) occupies only 3%. The whole range area is heavily overgrazed and shows very low productivity (about 150 kg dry matter $ha^{-1}$)[2]. Barley is cultivated in the area as a means for protecting the land from uncontrolled grazing (by intruders), i.e., as a tradition of claiming the ownership of land in the *Badia* area[2]. This has led to an increase in the area of better land that is used to cultivate barley, even though, with time, barley yields fall below vegetation yields of uncultivated rangeland. Thus, the current productivity of the transitional *Badia* area is much lower than the potential productivity, due to the above-mentioned biophysical conditions prevailing in the area, in addition to the following three factors[2]. First, what is known as 'free-for-all' grazing, which discourages any government or private investment in land improvement. Second, zero-input barley cultivation, leading to decreased infiltration, higher runoff and decreased yields. Third, land fragmentation and absentee land ownership, which prevents proper land management.

Incorporating water harvesting technologies in the current agro-pastoral system in the *Badia* was identified as a possible tool to sustain the agricultural productivity[4]. However, there were some obstacles in applying water-harvesting interventions, such as rainfall variability and the associated risk of failure, which might require more efforts to convince the farmers to adopt the JAZPP interventions. Therefore, the proposed land-use system must be flexible to cope with such practical challenges, and must consider the human component in order to be sustainable[7–9]. The production system must be economically and socially acceptable, and also nature- and environment-friendly. Public participation in land-use planning has many positive impacts, such as avoiding mistakes, avoiding conflicts among land users, and preventing irreversible damage to natural resources. There is a growing interest in promoting the interaction between all stakeholders and scientists, to decide on proper land use and management. Direct dissemination of knowledge in one way from scientists to farmers has proved ineffective[8,9].

The Participatory Rural Approach has been recognized as an essential ingredient to agricultural development; it begins with the recognition that farmers only adopt practices that meet their perceived needs. The process recognizes the need for communication links between all interested parties in defining goals, management policy, and solutions to problems[10]. With the current emphasis on environmental and economic sustainability of agriculture, there is a need for a more integrated approach. Participatory research helps to bring scientific methods and the integrated production needs of farmers together to develop practical, effective and carefully tested farming methods[11]. The objectives of this research were to investigate the possibility of adoption of the land-use alternatives by farmers, and to identify their suitability under field conditions.

## Approach and Methodology

### *Selection of suitable sites*

Selection of potential sites and farmers for field trials was based on the following criteria: the site should represent the typical prevailing conditions in the transitional *Badia* zone, it should be accessible and visible to as many members of the farming community as possible in order to maximize local awareness, and it should be currently cultivated by a cooperative farmer who lives in the area. The possible locations suggested by the various organizations, local people and/or field officers (from Agricultural Extension Departments) were visited and assessed. Sites were first assessed based on their physical suitability for the planned use, and then the willingness and ability of the owner(s) to cooperate with the program were verified.

The criteria used for the physical assessment included: *slope*, which determined which intervention(s) could not be installed; *soil depth*, which determined the suitable crop and how much water the profile could store; *rock outcrop*

**Table 1.** Different designs of water harvesting techniques used in the study.

| Intervention[1] | Width of catchment strip (m) | Width of cultivated strip (m) | Catchment : Cultivated |
|---|---|---|---|
| Contour ridges | 10 | 5 | 2 : 1 |
| Contour ridges | 15 | 5 | 3 : 1 |
| Contour furrows | 3 | 0.5 | 6 : 1 |

[1] Contour ridges, atriplex cultivated in contour ridges and barley in a part of the catchment area above ridges. Contour furrows, barley alone inside the contour furrows.

and *soil surface stone cover*, which have implications for tillage and cultivation; *infiltration rate/runoff*, as indicated by surface capping/absence of surface structure. In addition, the following social factors were also considered: *land fragmentation*, how many owners claimed title to the land; and *visibility/proximity*, to the target group (farmers).

Three broad zones of the *Badia* were included, the northern, central and the southern areas. The soils of these areas are derived from limestone and/or basaltic parent materials[12]. The elevation ranges from 700 to 1200 m above sea level. All proposed sites were visited and the following information was collected either from the field or extracted from the JOSCIS database[12]: location, elevation, soil series, precipitation, frost days, area available to install the intervention, soil salinity, surface capping, surface cracking, erosion, stone cover, rock outcrop, slope steepness and curvature, previous and current land use, population density, families on land, family size, livestock, total land holding and fencing requirements. The information collected was used to undertake a potential land suitability assessment for the intended Land Utilization Type (water-harvesting intervention).

The purpose of the field trials program was explained to owners of the sites that were considered suitable. The decision about including the farmers' land was taken based on the farmers' willingness for cooperation, the proportion of land that could be used for the trial without putting the farm under risk (minimum of 1 hectare), capability of farmers to maintain and protect the trial, and sufficient family labor support. In total, some 38 sites were initially assessed.

Of these 38 sites, 24 sites were rejected outright for various reasons; some sites were physically unsuitable; some sites had an obvious ownership and/or land fragmentation problems; and some were not accessible and therefore not visible by the farming community. Biophysical suitability and socio-economic factors were both considered in determining the overall suitability of the site. Only 14 sites continued to the end of the first season. Details about the implementation of the four interventions are explained in the following paragraphs.

**Micro-catchments for tree crops (*Negarim*).** Many sites were identified as suitable for micro-catchments based on biophysical criteria. However, several sites were deemed unsuitable due to ownership and/or land fragmentation problems, which resulted in implementing this intervention in only seven sites. The FAO formula[13] was utilized to design the size of the micro-catchment diamond, which ranged between 64 and 144 $m^2$. The micro-catchments were constructed using soil ridges (30 cm wide and 40 cm high). The tree seedlings were planted in an infiltration pit that was excavated at the lowest point within each micro-catchment.

**Contour ridges for atriplex (*Atriplex nummularia* L.) and barley.** Considering the biophysical factors, there was no difficulty in locating suitable sites for contour ridges. Land ownership (multiownership) was not an important reason to reject the site for this intervention. The situation was different with trees since farmers consider tree cultivation as a permanent occupation of part of the land, which complicates the later subdivision of the whole parcel between the owners. Therefore, at sites where land was owned by more than one farmer, it was recommended that contour ridges are more suitable, even when the land was physically better for micro-catchments.

The basic principle of using *catchment/cultivated area* ratios[13] was used to calculate the spacing between contour ridges, with some adjustments to consider the effect of slope steepness[14]. One strip of 5-m width was cultivated and sown with barley immediately upslope from each furrow, while the area above this was left bare to act as the catchment area. Basically, contour ridges are meant to be cultivated with atriplex only; however, due to farmers' insistence, the design was modified to accommodate barley. The sites' installation was carried out based on three different designs detailed in Table 1. Contour ridges for atriplex with barley were installed in five sites.

**Contour furrows for barley.** Barley was cultivated in deep furrows at three sites that were selected from the five sites where contour ridges were established. Furrows (30 cm wide and 30 cm deep) were made using a moldboard plow, and barley seeds were sown inside the furrows according to the specifications listed in Table 1.

**Water spreading.** The study area contains what is known as *Marrabs*, narrow areas of silty alluvial flat *wadi* bottoms that experience natural water spreading during and after periods of rainfall. Surface characteristics of some *Marrabs* are favorable for cultivation and plant growth. Although the total area of *Marrabs* is limited, appreciable biomass can be produced from these areas.

Installing a few stonewalls perpendicular to the direction of stream flow facilitates the spreading of water outside the *wadi* bed to flood the surrounding area, which allows time for water to infiltrate into the soil, thus increasing stored water in the profile. Owing to these strict site requirements for water spreading techniques, only two sites were found suitable. The spacing between stonewalls was 8 m, which was based on the calculation using the FAO methodology[13] with some adjustments to account for surface capping and surface stoniness that are important features in the Jordanian *Badia* area[5].

### Monitoring and evaluation of interventions

A number of field officers were trained to monitor, control and collect data about the interventions. Contact with farmers was maintained before and after the installation of the interventions through routine visits by researchers and field officers to monitor the performance of the crop or vegetation being grown and the manner in which the test site was managed and maintained, and to respond to any practical or technical questions raised by the farmer. Farmers were visited regularly every 2 weeks. Extra visits were encouraged after any significant rainfall event, in case there was unexpected damage, or during periods of poor rainfall, in case advice on limited supplementary irrigation (from nearby wells) had to be given.

The following aspects were recorded during each monitoring visit: precipitation, irrigation (if any), status of the catchment area, status of the collection area, damage (cause and need for maintenance), and visual estimates of crop performance. Three field days, attended by collaborators (NGOs, local organizations and leaders) and other innovative farmers, were organized to demonstrate what the project had achieved and to gauge the farmers' reactions to the success or otherwise of the measures implemented. Dissemination strategies might benefit by including such farmers in leadership roles in the initial stage of education programs[15].

## Results and Discussion

The late start of rainfall during the first season (toward the end of December) adversely affected the Project activities, particularly in the south (Sites 1, 2, 26, 27 and 28). Total rainfall was only 113 mm, which was below the long-term average (150 mm). Moreover, the rainfall occurred mainly as small showers, which were ineffective in generating runoff for water harvesting. The proportion of rain events leading to significant runoff was much lower than normal. Runoff coefficients were approximated using results from previous research[16]. The overall approximated runoff coefficient did not exceed 23% of the total rainfall, which was lower than the 15-year average (33%). A long dry period in late February through March and a prolonged period of higher than normal temperatures led to relatively poor crop growth over this period.

### Trials results

Considering the late start of the rainy season, lower rainfall and much lower runoff volumes than average, the performance of the trials (crop stand, density and survival rates) was encouraging compared with the surrounding fields, as evaluated by farmers, Extension officers, and other observers. A summary of intervention status during the first and the second seasons is presented in Table 2.

**Micro-catchments for tree crops (*Negarim*).** These interventions were implemented successfully, and growth of tree seedlings appeared encouraging (Fig. 2a). At the end of the first season, all interventions were successful with survival rates between 95 and 100% (Table 2). This proved that these interventions performed well from a technical (biophysical) point of view. The close monitoring by project staff, good protection and guarding of the sites and the benefit of limited supplementary irrigation (during the establishment stage) helped in this success, even with low rainfall amounts. In the second season, where farmers were fully responsible, without any monitoring by project staff, the outcome was not as successful; three sites were total failures (Sites 1, 2 and 28, survival 0%), two sites were relatively successful (Sites 24 and 34, survival 70%), and only two sites were successful (Sites 9 and 26, survival 100%).

The unsuccessful sites were abandoned by the farmers for different reasons, mainly because the cultivated land was only part of a land parcel owned by many owners. None of the owners felt responsible for that particular land, and therefore no protection or maintenance was provided, which resulted in damage by livestock. Fencing alone without guarding was not enough to avoid the damage. This highlighted the importance of social factors in the sustainability of the water-harvesting interventions; technically successful intervention could fail without farmers' input.

In another situation (Site 28), the land was owned by one farmer and the intervention failed. The land was assessed as suitable for contour ridges but the farmer insisted in installing micro-catchments with olive (*Olea europaea* L.) trees, because the land was an extension to an already existing irrigated olive farm. The performance of olive trees under water harvesting was unsatisfactory for the farmer. Therefore, the farmer decided that this intervention was a waste of his land, while he could cultivate it with a higher number of trees under irrigation, although from an unsustainable water source (groundwater resources). This indicates that while it is important to screen the land-use alternatives against the farmer's priorities and wishes, the biophysical suitability of land for certain purposes must not be ignored. Alternatively, compromised solutions must be found between both aspects whenever they are in conflict.

Absence of proper maintenance during the second season was the main reason for the relative failure of two sites. Losing interest and enthusiasm due to either ownership complications or no obvious benefits in the short-term

**Table 2.** Intervention status during the two growing seasons.

| Site no. | Intervention and crop[1] | Location (city) | Rainfall (mm) | | Irrigation (liters per tree) | | Survival/ germination (%) | | Crop height (cm) | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | |
| 1 | MC/Olive | Al-Karak | 165 | 170 | 40 | 0 | 100 | 0 | 50 | 0 | Multiownership, no guarding and/or protection, damage by livestock |
| 2 | MC/Almond | Al-Karak | 165 | 170 | 40 | 0 | 100 | 0 | 50 | 0 | Multiownership, no guarding and/or protection, damage by livestock |
| 9 | MC/Olive | Al-Muwaqqar | 127 | 149 | 0 | 0 | 95 | 95 | 99 | 115 | Successful, single owner |
| 24 | MC/Olive | Abu-Furth | 94 | 128 | 60 | 0 | 100 | 70 | 80 | 80 | Successful even without farmer's input |
| 26 | MC/Olive | Al-Karak | 165 | 170 | 60 | 50 | 100 | 100 | 50 | 95 | Successful, interested farmer |
| 28 | MC/Olive | Al-Karak | 165 | 170 | 60 | 0 | 100 | 0 | 50 | 0 | Suitable for CR but farmer demanded MC |
| 34 | MC/Olive | Al-Muwaqqar | 127 | 149 | 0 | 0 | 100 | 70 | 65 | 70 | Multiownership complication, no maintenance |
| 18 | CR/Atriplex and barley | Al-Mafraq | 149 | 205 | 0 | 0 | 70 | 0 | 70 | 0 | Suitable for MC but farmer demanded CR |
| 19 | CR/Atriplex and barley | Al-Mafraq | 149 | 205 | 0 | 0 | 75 | 30 | 60 | 80 | Successful even without farmer's input |
| 23 | CR/Atriplex and barley | Abu-Furth | 94 | 128 | 0 | 0 | 86 | 0 | 40 | 0 | No guarding and/or protection, damage by livestock |
| 27 | CR/Atriplex and barley | Al-Karak | 165 | 170 | 0 | 0 | 95 | 0 | 45 | 0 | Farmer demanded MC with trees |
| 33 | CR/Atriplex and barley | Al-Muwaqqar | 127 | 149 | 0 | 0 | 50 | 0 | 60 | 0 | Multiownership, no guarding and/or protection, damage by livestock |
| 22 | Spreading | Abu-Furth | 94 | 128 | 0 | 0 | 0 | 70 | 0 | 20 | Late installation in first season, good crop stand in second season |
| 31 | Spreading | Al-Muwaqqar | 127 | 149 | 0 | 0 | 70 | 80 | 45 | 30 | Successful even with multiownership and without maintenance |

[1] Intervention and crop: MC, micro-catchments; CR, contour ridges.

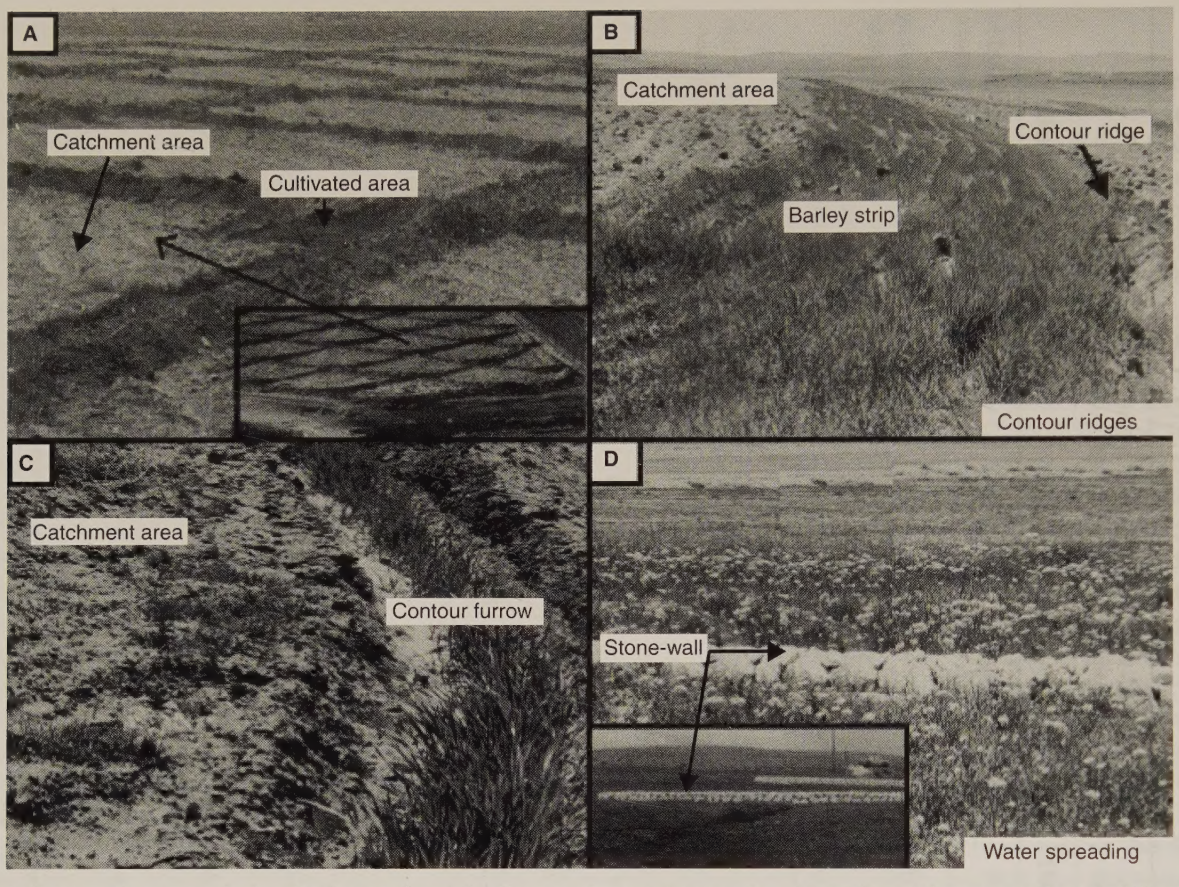


**Figure 2.** Intervention status during the first season. (A) Micro-catchments intervention shows the catchment area for rainfall collection and cultivated area (inset: general view of the micro-catchments intervention); (B) planting atriplex in contour furrows with barley in a part of the catchment area; (C) barley in contour furrows with no planting in the catchment area; (D) stone walls installed perpendicular to the stream bed to spread the water (inset: general view of water spreading technique).

was behind the farmers' ignorance of these interventions. However, the relative success of these interventions, even without maintenance, indicated their technical validity. Regarding the two successful sites, each of them was owned by an interested and enthusiastic sole owner. Both owners were taking the lead in maintaining and protecting the intervention. Such cases emphasized that whenever socio-economic and biophysical factors are compatible, successful implementation of new land-use alternatives is more likely. The merits of such an approach have been emphasized by others[17].

This study indicated that micro-catchments should be constructed based on an appropriate design[13] and that bunds must be compacted firmly, especially in lower areas of the diamond to avoid damage by accumulated runoff water. Continuous checking of the bunds is necessary, especially in the first season and after each appreciable rainfall event. Based on field observations, infiltration pits must be sufficiently low to collect all runoff, especially for those rainfall events with high amount and/or intensity. During the first two seasons, limited supplementary irrigation is essential, especially in dry periods, in order to increase the rooting depth as much as possible and to keep seedlings alive. Annual crops (vegetables) could be cultivated in the infiltration pits during the first few years to provide some income for the farmers until the trees start production. The layout of the micro-catchments should allow access for tractors to facilitate occasional irrigation without causing damage. Open diamonds, oriented on the contour every 20–30 m, could be the solution to this problem. Protecting the intervention from grazing (by fencing and guarding) highly improved the regeneration of natural vegetation; similar conclusions were stated by the JAZPP project[2]. Therefore, continuous weeding is required both in the catchment area and in the infiltration pit. Using the weeded vegetation as animal fodder compensates for the weeding costs.

The cost of site protection using a fence was relatively high (about 75% of the total implementation cost), and hence, it is a serious obstacle for implementation. Cheaper alternatives are thus required because fencing is vital to protect the planted trees from grazing by livestock. Such alternatives could be one or more of the following: (1) undertaking micro-catchment intervention over a large area, so that the perimeter-to-area ratio is low; this could be implemented by adjoining farmers; (2) select sites to implement this intervention to be close to the village, so that animal movements would be quickly seen; (3) growing

cactus as a live fence, which is also a source of income, with the cactus itself being supplied with harvested water; (4) in areas where stone is easily available, and especially where family labor is possible, install stone walls, with or without a strand of barbed wire along the top of the wall, .

**Contour ridges for atriplex and barley, and contour furrows for barley.** These interventions were successful in improving the productivity of atriplex and barley as well as in restoring many plant species, Figures 2b and 2c are examples. No fencing was required to protect the sites, and therefore the cost of installation was relatively low. This is because the cultivation of barley is traditionally used to claim land ownership and, therefore, protects the land from intruders. The crop stand, density and survival rates were compared with adjacent lands that were cultivated by the farmers using traditional seeding methods (without water-harvesting measures). Overall, the density and stand of barley cultivated using these interventions were much better than those of barley cultivated in adjacent untreated land. The farmers also acknowledged these observations during the field days, which are explained later.

The above results, at the end of the first season, indicated good performance and suitability of these interventions to the study area. In the second season, however, the results were less successful; the farmers cultivated only one out of the five sites. In two of these sites (Sites 18 and 33), the land was assessed as suitable for micro-catchments (slope $< 3\%$) but farmers insisted on contour ridges, mainly because of ownership complications, where farmers think about tree cultivation as a 'permanent' land-utilization type. Even with installing what the farmers think as a suitable intervention, the fact that the land is owned by many farmers resulted in ignoring the intervention, and consequently no maintenance or protection was provided by the farmers. This might be due to the fact that only one of the landowners was approached and all agreements and explanations about the intervention were discussed only with him. Thus, approaching all owners would, in retrospect, have been a better alternative in order to get their approval for the work.

In another site (Site 27), the farmer wanted micro-catchments with olive trees to complete an already existing olive farm. The assessment of the land indicated total unsuitability for olive trees, and therefore barley was cultivated in that land. With low rainfall, and consequently low productivity of barley, the farmer lost interest and abandoned the intervention. The lesson learned is that a change of land-use type to a new, more suitable one, but without the farmer's agreement, is doomed to failure. Again, a compromise should be achieved between biophysical land suitability and farmers' needs and wishes in order to introduce these new interventions successfully. It has been indicated that the development of new technologies for farming systems can be greatly enhanced through more extensive use of participatory research[11].

Technically, there are some important outcomes from these interventions. Contour ridges planted with atriplex were less successful when barley was planted in a part of the collection area. However, farmers insist on cultivating barley as a means of protecting the land from any livestock grazing. Therefore, it would be rational to recommend the plantation of barley only on a limited part of the collection area, with atriplex cultivated in the contour ridges. The percentage of the collection area planted with barley could be progressively increased when the atriplex rooting system is well established. An example of this was observed in Al-Mafraq site where the farmer cultivated the whole field with barley and the atriplex shrubs in contour ridges were still very vigorous and productive during the second season. It is also possible to cultivate barley in contour furrows without atriplex, but with a wider furrow bed (80–100 cm) than the one used in this study (only 30–40 cm), in order to accommodate more seeds. Developing a machine to construct furrows with these dimensions and to plant barley at the same time is needed to popularize this technique.

Continuous maintenance of contour ridges is required throughout the rainy season to avoid erosion and losses of collected water. Small earth ties are needed every 5 m along the contour ridges or deep furrows to gain better water distribution uniformity. Continuous weeding of the collection area greatly improves the productivity of atriplex. The protection of shrubs, especially during the first season, is an important issue. Again, cheap alternatives, such as spiny varieties of cactus, must be considered for protection purposes.

**Water spreading.** Water spreading was very successful when practiced inside Al-Muwaqqar experimental station, where intensive vegetative cover was generated[2]. In the farmers' fields, the implementation faced some obstacles during the first season, but, with good design on suitable sites, this technique proved to be highly successful (Fig. 2d); the vegetative cover was much better than that of the surrounding un-flooded areas. The fine holes between large stones were closed using gravel so that water flow was sufficiently reduced. The construction cost was relatively high but can be reduced using the available family labor, especially when stones are locally available. The results indicated that, due to a large amount of runoff generated, the catchment area should not exceed 10 hectares when stonewalls are implemented. For areas larger than this, earth bunds with small concrete spillways can be considered, but are costlier.

## *Assessment by farmers*

Assessment by farmers was organized around three field days, undertaken at Mafraq, Muwaqqar and Abu-Furth (Fig. 1). In addition, farmers' comments were recorded during the regular field visits and were very important in clarifying everyday problems as well as long-term difficulties or benefits of each intervention. In general, farmers were impressed by what they observed, and most of

them expressed willingness to cooperate with similar projects in the future. Discussion by farmers included the following points: protection of the atriplex from grazing in the first and second year is essential; barley in the collection area would have to be cut manually during these 2 years, and not grazed directly by livestock; most farmers prefer using the local two-row variety of barley (Baladi) and not the new varieties that were used in the trial sites (Rum and ACSAD), which may produce higher yield, but were not preferred by the farmers because they consider them less palatable.

The relative merits of cultivating the collection area to barley generated much discussion. The farmers initially considered areas left without any crop (catchment area) as being a waste of land. However, the researchers explained the importance of this area in duplicating the amounts of water available for crops and the consequent increase in yield, which should compensate for the uncultivated land. The above comments were never thought about by the team of researchers, which highlighted the role of farmers in determining important aspects of the intervention details. These field days were also effective in disseminating the knowledge about these interventions, which enhances their adoption by the farmers' community. Even under different conditions, previous research indicated that field tours were a successful means of technology transfer among participants[17].

## Conclusions and Recommendations

The study indicated that the suggested water-harvesting interventions are biophysically suitable and could be implemented in the study area. However, considering both socio-economic aspects and biophysical suitability is indispensable to assure successful selection and implementation of new water-harvesting interventions. Special attention should be given to the land ownership, especially the multiownership regime, which is common in Jordan. Prior to any implementation, a clear idea about these interventions should be given to all concerned owners and, consequently, their agreement and feedback are necessary to avoid any future conflict and to ensure their active participation.

Farmer's participation through regular field visits and field days is a successful tool for the dissemination of the tested interventions. Farmers showed willingness to be involved in future project activities. This participation had a crucial role in highlighting some practical problems that were overlooked by researchers. A recurrent problem for water harvesting is site protection. Unless this problem can be overcome by cheap fencing, these interventions will be difficult to maintain. The study recommended some practical alternatives to provide protection. The study also highlighted important practical and technical considerations that help in ensuring successful implementation of these interventions in the farmers' fields. Extension officers should work closely with interested farmers to provide advice about the selection, implementation and monitoring of various types of water-harvesting interventions. Farmers' needs and capabilities must form the basis for any decisions about land use. Our experience showed that successful intervention might easily fail due to small but overlooked socio-economic constraints.

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# Weed suppression with hydramulch, a biodegradable liquid paper mulch in development

J.P. Warnick[1], C.A. Chase[1,*], E.N. Rosskopf[2], E.H. Simonne[1], J.M. Scholberg[3], R.L. Koenig[4] and N.E. Roe[5]

[1]Horticultural Sciences Department, University of Florida, 1301 Fifield Hall, PO Box 110690, Gainesville, FL 32611-0690, USA.
[2]USDA, ARS, USHRL, 2001 South Rock Road, Fort Pierce, FL 34945, USA.
[3]Agronomy Department, University of Florida, PO Box 110500, Gainesville, FL 32611-0500, USA.
[4]Rosie's Organic Farm, Gainesville, FL 32607, USA.
[5]Farming Systems Research, Inc., Boynton Beach, FL 33437, USA.
*Corresponding author: cach@ifas.ufl.edu

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## Abstract

Cost-effective, laborsaving, and environmentally sound weed management practices are needed for sustainable vegetable production. Organic production, in particular, precludes the use of synthetic herbicides and requires that organic farmers utilize practices that reduce harmful environmental impact. Although polyethylene film mulch is used extensively in vegetable production in Florida, its use has a number of drawbacks, among which is the susceptibility of opaque polyethylene mulch to penetration by yellow and purple nutsedge. Appreciable labor and disposal/environmental costs are associated with its removal. A durable mulch material that would effectively control nutsedge and other weeds but with no associated environmental and disposal costs is highly desirable. Hydramulch, a paper-like material applied as a slurry consisting of cotton waste, newsprint, gypsum and a proprietary adhesive, was tested as a biodegradable alternative to polyethylene mulch during the spring of 2003. Experiments were conducted in southeastern and north-central Florida to compare the effects of three hydramulch formulations, polyethylene mulch and a no mulch control on soil temperature, soil moisture and weed infestation. Soil temperature under hydramulch was 1–4°C lower than that under polyethylene. In the absence of rain, the use of hydramulch resulted in soil moisture levels that were 1–4% lower than with polyethylene mulch. Higher soil moisture with hydramulch than polyethylene was coincident with rainfall. Hydramulch remained intact on most beds and suppressed broadleaf weeds and grasses, particularly at the north-central site where the mulch was applied at a greater thickness. However, purple nutsedge readily penetrated hydramulch. Therefore, hydramulch may be applicable for use for the suppression of broadleaf weeds and grasses at sites with little or no nutsedge pressure in fall or in crops for which cooler soils are desirable or crops that are rainfed or overhead irrigated.

**Key words:** hydramulch, biodegradable, mulch, organic, weed management

## Introduction

Weed control is a primary concern for vegetable growers, and for organic growers in particular it ranks among their highest priorities, according to the Organic Farming Research Foundation[1]. Yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*C. rotundus*) are prevalent and prolific weeds in Florida. These weeds are difficult to control even in conventional vegetable production because of underground perennating organs or tubers. The pointed apices of rhizomes that sprout from tubers very effectively penetrate opaque polyethylene film mulch. The tubers provide the needed source of energy for the weed to sprout, and then the sharp tips of the leaves penetrate the polyethylene film[2].

Black polyethylene film (or white with a black underside) mulch is used extensively in vegetable production. Benefits include weed growth inhibition, increases in soil temperature leading to faster crop development and earlier harvests, reduction in the rate of fumigant loss as a result of

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the water layer that is formed beneath the mulch, and fruit protection from rain-splash and soil organisms[3]. However, the use of polyethylene mulch has several limitations and disadvantages. Removal of polyethylene film from the field is costly and its disposal has become an environmental concern where landfill space is scarce[4]. In 1995, annual polyethylene mulch use in US agriculture was reported to be approximately 110 million kg with an estimated removal and disposal cost of US$125–175 $ha^{-1}$.[5] In 2004, the use rate had increased to 130 million kg per year with disposal costs of about $250 $ha^{-1}$.[6]

Polyethylene mulch acts as a water-impermeable layer over up to 75% of a planted field, causing water and agrochemical runoff into nearby water systems and thereby increases environmental impacts on nearby watercourses and lakes[7]. A study that compared the off-site translocation of soil and agrochemicals between tomato plots under polyethylene mulch and a residue mulch of hairy vetch (*Vicia villosa*) indicated significantly greater quantities of pesticide runoff with the polyethylene mulch[8].

Also, opaque polyethylene film does not effectively suppress nutsedge unless a soil fumigant has been applied. Methyl bromide in mixtures with chloropicrin has been widely used to control weeds and soil-borne diseases in conventional plasticulture vegetable production. However, as stipulated by the Montreal Protocol, the production and import of methyl bromide was banned on 1 January, 2005, in developed countries[9]. The loss of methyl bromide is likely to result in yellow and purple nutsedge becoming increasingly important weed problems in conventional vegetable production[10].

Transparent polyethylene film mulches are less prone to penetration by yellow and purple nutsedge than opaque polyethylene film because leaf expansion occurs under the clear film when rhizome tips detect light as they emerge from the soil[11]. Rhizome elongation ceases and elongating nutsedge leaves become trapped beneath the clear film. This photomorphogenic response has also been demonstrated with infrared-transmitting film and silver film, which transmit low levels of light and are thus considered translucent[12]. Translucent mulches resulted in a 70–88% reduction in purple nutsedge penetration compared to opaque mulches.

Effective and environmentally sound alternatives to polyethylene mulch are needed. One option is paper mulch. Paper mulch can be applied using standard polyethylene film application equipment with minimal adjustments[6]. The difficulty has been in developing a paper product that can remain intact throughout the growing season[4]. Paper loses much of its strength when wet and degrades too quickly where it is embedded in the soil to be effective for season-long weed control. Degradation of paper mulches before the end of the cropping season commonly occurs, resulting in limited adoption among growers[13]. Paper is also prone to removal by wind. However, brown kraft paper coated with vegetable oil-based resins (linseed or soybean oil with a cobalt octoate catalyst solution) is more durable than noncoated paper[4]. Paper coated with vegetable oil resin maintained its integrity for a single crop of watermelon and resulted in yields that were statistically similar to those obtained with polyethylene mulch[6]. Coating paper with a biodegradable polymer on both sides or on the underside also considerably decreased the rate of degradation[14,15]. However, at low yellow nutsedge population, no difference in nutsedge plant density was observed with paper and polyethylene mulch[14], but yellow nutsedge was more effectively suppressed by paper mulches than by polyethylene mulch with a relatively high nutsedge population[6]. Because of the short duration of persistence and because it cannot be used as a fumigation tarp, paper mulch may be adopted for commercial use primarily by organic growers.

Other potential alternative mulches for weed management are biodegradable materials that are applied as slurries: foam mulch, hydraulic mulches and hydramulch. Foam mulch consists of: recycled cotton and cellulose fibers, gums and starches, surfactants and saponins, pigments, fertilizers and buffers[16]. This material maintained its integrity throughout the growing season and provided broadleaf and grass weed control similar to that of black polyethylene mulch.

Hydraulic mulch slurry, derived mainly from wood by-products, is sprayed onto the soil surface as a biodegradable ground cover to prevent erosion and establish vegetation. Liburd et al.[17] tested hydraulic mulch materials and reported that humidity and regular rainfall resulted in softened mulches that could be easily penetrated by weeds. The authors concluded that hydraulic mulch could potentially control weeds provided that an effective adhesive was added to ensure that the material maintains a rigid structure during moist conditions.

Hydramulch (Novovita Inc., Raleigh, NC), the subject of the current study, is a variation of hydraulic mulch that is composed of cotton waste and newsprint, with gypsum as a filler (for improving texture) and bound by proprietary adhesive. Hydramulch slurry dries within 12 h of application, forming a gray shell with a texture similar to the old-style egg cartons made from paper by-products. Potential benefits of appropriate use of hydramulch may be as a durable, biodegradable mulch that can remain intact and effective throughout the growing season and the successful control of nutsedge with applicability for sustainable conventional production systems. Discussions between the manufacturer and the National Organic Standards Board about the suitability of hydramulch for use in organically certified acreage are ongoing. The components of the mulch are considered individually acceptable; however, the process of mulch production is in review for consideration as a nonsynthetic substance.

The objectives of this study were to determine the suitability of hydramulch for weed control and to compare the effect of three formulations of hydramulch on soil temperature, soil moisture and weed growth with polyethylene film mulch and bare ground.

## Materials and Methods

Hydramulch was tested in Florida during the spring of 2003 at two locations: an organic farm in Gainesville (north-central Florida) and a conventional farm in Loxahatchee (southeast Florida). These two sites differed in nutsedge pressure, soil type, temperature, humidity and rainfall. Treatments consisted of three hydramulch formulations (HM1, HM2 and HM3), polyethylene film mulch and a bare soil (no mulch) control. Hydramulch formulations differed in the quantity of shredded newsprint and gypsum used: HM1—55% newsprint, 32% gypsum and 13% cotton by-products; HM2—45% newsprint, 43% gypsum and 12% cotton by-products; HM3—39% newsprint, 49% gypsum and 12% cotton by-products. All formulations contained the same percentage of the manufacturer's proprietary adhesive (Novovita Inc.). Hydramulch slurry was applied using a 750 gallon Turbo Turf Hydro Seeder (Turbo Technologies, Inc., Beaver Falls, PA) powered by a 27 horse power gas engine. A 1.25 inch inside-diameter wound-fiber-reinforced PVC hose with a smooth bore was used to deliver the slurry at a rate of 1 $m^3$ per 50 linear bed meters at Loxahatchee and 2 $m^3$ per 50 linear bed meters at Gainesville.

**Loxahatchee.** Hydramulch slurry was applied on 17 February in Loxahatchee and dried to give a 2 mm-thick mulch. The experimental design was a randomized complete block with four replications. Ten raised beds were positioned north–south. Each plot was 6.1 m in length and 1 m wide with 1 m alleys separating plots along beds. Beds were irrigated with two drip tapes (Queen Gil International, Israel) per bed, 30 cm apart, and positioned approximately 2 cm below the soil surface. The flow rate was 4 $l\,h^{-1}$ per linear meter bed length, with drip emitters located 10 cm apart. Irrigation occurred daily at 6:00 am and 6:00 pm for 45 min unless it rained. The white-on-black polyethylene film mulch (Sunoco, Philadelphia, PA) was 0.032 mm thick. The soil type was classified as Riviera Sand (loamy, siliceous, hyperthermic Arenic Glossaqualfs), a poorly drained soil with 1–2% organic matter, and reaching a depth of 50–100 cm above a loamy subsoil. The field capacity of Riviera Sand is 4–6% in the top 15 cm, and 3–5% to a depth of approximately 70 cm.[18,19]

**Gainesville.** In Gainesville, hydramulch slurry was applied on 21 March at double the volume, resulting in a mulch approximately 4 mm thick (added thickness intended to improve durability). Treatments were applied to 3 m-long beds oriented north–south, with four replications in a randomized complete block design. Irrigation was provided via one drip tape (T-Tape) per bed buried 2 cm below the soil surface. Irrigation was used to supplement rainfall. The soil type was a Millhopper sand with 1–2% organic matter and a field capacity of 6–12% in the top 20 cm, and 5–6% for the subsoil[19]. Black 0.025 mm-thick polyethylene film mulch (Helena Chemical, Collierville, TN) was used in Gainesville.

**Data collection.** Volumetric soil moisture was measured at 2-week intervals on 2 March, 15 March, 30 March, 13 April and 26 April in Loxahatchee; and 28 March, 12 April, 23 April, 7 May and 20 May in Gainesville. A portable time domain reflectometry (TDR) probe (Hydrosense model, Decagon Devices, Pullman, WA) was used to take four readings at 20-cm depth in the central section of each plot that excluded a 61 cm border at each end. Soil temperatures at 10-cm depth were measured in two replications at 30 min intervals with CR10 dataloggers (Campbell Scientific, Logan, UT) equipped with copper-constantan thermocouples. Soil temperatures were measured from 1 March to 31 May at Loxahatchee and from 5 April to 15 June at Gainesville. Daily maximum, minimum and mean temperatures were calculated.

Weed density and biomass in each plot were assessed using a randomly placed quadrat with dimensions of 76.2 cm × 76.2 cm. Weeds were counted and categorized as broadleaf, grasses and nutsedge on 2 March, 15 March, 30 March, 14 April and 27 April in Loxahatchee and on 29 March, 15 April and 3 May in Gainesville. Fresh above-ground weed biomass was determined in Loxahatchee on 30 May and in Gainesville on 12 June. The weed biomass was dried at 75°C to a constant weight and weighed again to obtain dry biomass. All weed species were combined at the Loxahatchee site (due to a low nutsedge population), while nutsedge, grasses and broadleaf weeds were weighed separately at the Gainesville site in order to quantify the impact of the substantial purple nutsedge population.

Data were analyzed by location. Analysis of variance (ANOVA) was performed using the general linear model approach of SAS®[20] and the level of significance used was 5%. Contrasts were used to test preplanned comparisons of treatment means.

## Results and Discussion

### *Soil temperature*

**Loxahatchee.** Maximum and mean soil temperatures beneath white-on-black polyethylene mulch were consistently 1–3°C warmer than beneath hydramulch (Table 1). From 1 March to 19 April, maximum soil temperature was 1.4°C warmer than with the hydramulch treatments and mean soil temperatures were 1.0°C warmer. Between 26 April and 31 May, the difference in temperature had increased to 3.3 and 1.5°C, respectively. The trend with nonmulched soil was somewhat different. From 1 March to 19 April, maximum and mean temperatures of non-mulched soil were 1.0 and 0.6°C higher than soil temperatures under hydramulch; however, between 26 April and 31 May, maximum and mean temperatures of nonmulched soil were cooler than with hydramulch treatments by 1.6 and 0.6°C, respectively. Minimum soil temperatures were consistently warmer under polyethylene than under hydramulch.

**Gainesville.** From early April to mid-June, maximum, minimum and mean soil temperatures were warmer with

**Table 1.** Comparative effect of mulch type on daily soil temperatures (maximum, minimum and mean) in Loxahatchee and Gainesville recorded at 30-min intervals at a depth of 10 cm.

| | Loxahatchee | | | | | |
|---|---|---|---|---|---|---|
| | 1 March to 19 April | | | 26 April to 31 May | | |
| Mulch treatment[1] | Max. | Min. | Mean | Max. | Min. | Mean |
| | °C | | | | | |
| No mulch | 28.5 | 22.3 | 25.1 | 27.2 | 24.7 | 25.9 |
| HM1 | 27.5 | 22.3 | 24.7 | 28.7 | 24.8 | 26.6 |
| HM2 | 27.6 | 21.9 | 24.4 | 28.8 | 24.3 | 26.4 |
| HM3 | 27.5 | 22.1 | 24.5 | 29.0 | 24.5 | 26.5 |
| Polyethylene | 28.9 | 22.8 | 25.5 | 32.1 | 24.9 | 28.0 |
| *P*-value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Contrasts | | | | | | |
| NM versus HM | ** | NS | ** | ** | * | ** |
| HM versus PE | ** | ** | ** | ** | ** | ** |
| Among HM | NS | NS | ** | NS | ** | * |
| | Gainesville | | | | | |
| | 5 April to 12 May | | | 13 May to 15 June | | |
| No mulch | 27.7 | 21.5 | 24.2 | 26.9 | 23.9 | 25.2 |
| HM1 | 26.2 | 21.5 | 23.5 | 28.0 | 24.5 | 26.0 |
| HM2 | 26.4 | 21.7 | 23.7 | 27.0 | 24.5 | 25.7 |
| HM3 | 27.2 | 21.8 | 24.1 | 27.7 | 24.6 | 26.0 |
| Polyethylene | 30.5 | 23.4 | 26.5 | 30.8 | 25.8 | 28.0 |
| *P*-value | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Contrasts | | | | | | |
| NM versus HM | ** | * | ** | ** | ** | ** |
| HM versus PE | ** | ** | ** | ** | ** | ** |
| Among HM | ** | * | ** | ** | ** | ** |

[1] NM, HM, and PE are no mulch, hydramulch and polyethylene mulch, respectively. White on black polyethylene was used at Loxahatchee and black polyethylene at Gainesville. Contrasts are designated NS when nonsignificant.
* and ** indicate significance at 0.05 and 0.01 levels, respectively.

black polyethylene mulch than with the hydramulch treatments by 1–4°C (Table 1). Nonmulched soil was warmer than soil under hydramulch by approximately 1°C for maximum and mean temperatures. Differences in maximum and mean soil temperatures were recorded among the hydramulch treatments. During April and the first half of May, soil temperature increased as the proportion of newsprint and gypsum in the hydramulch formulations increased and declined, respectively. However, this same pattern did not hold true from 13 May to 15 June.

Colored polyethylene mulches can be used to modify soil temperature to improve crop growth and yield. The optimum soil root zone temperature for tomato has been shown to be approximately 26°C[21]. Mulches that result in soil temperatures closest to the optimum gave the best plant growth and yields. Black polyethylene film mulch results in higher soil temperatures than nonmulched soil[22–25]. In north Florida where black polyethylene mulch is used in spring to promote soil warming, the cooler temperatures under hydramulch may be a limitation. Soil temperatures with white-on-black polyethylene mulch tend to be lower than with black mulch[25,26]. Therefore, white-on-black mulch is typically used instead of black mulch in spring in south Florida and in fall in north Florida to obtain cooler soil temperatures. Hydramulch could prove beneficial at moderating soil temperatures during the hot weather in Florida. This moderating effect may be similar to that reported with organic mulches, which exhibit smaller diurnal fluctuations in temperature than polyethylene mulch[13,22] and is thought to be due to insulating action[13].

## *Soil moisture*

In Loxahatchee, moisture levels of 7–10% for most readings were near field capacity range for this slow draining soil (Riviera sand). Soil moisture levels at the bed edge were similar for all treatments (Table 2). In the center of the beds, soil moisture with polyethylene was 1–2% greater than soil moisture with the hydramulch treatments on the third and fourth sampling dates (30 March and 13 April). The soil moisture levels on sampling date 5 (26 April) greatly exceeded field capacity because of heavy rains. As a result, soil moisture under hydramulch was greater than with the polyethylene mulch at the centers of

**Table 2.** Effect of mulch type on soil moisture (%) measured at 2-week intervals at 10 cm depth on bed edges and centers.

| | Sample dates[1] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | |
| **Mulch treatments** | **Edge** | **Ctr** | **Edge** | **Ctr** | **Edge** | **Ctr** | **Edge** | **Ctr** | **Edge** | **Ctr** |
| | | | | | **Loxahatchee** | | | | | |
| No mulch | 6.6 | 8.0 | 9.4 | 10.3 | 9.9 | 9.4 | 7.3 | 8.1 | 18.1 | 16.4 |
| HM1 | 7.7 | 7.8 | 8.5 | 10.1 | 8.8 | 9.9 | 8.3 | 8.3 | 17.6 | 19.3 |
| HM2 | 7.2 | 9.4 | 9.0 | 14.1 | 11.3 | 10.4 | 8.2 | 9.6 | 20.3 | 21.1 |
| HM3 | 6.6 | 7.7 | 8.4 | 9.1 | 9.0 | 9.8 | 6.8 | 7.5 | 18.1 | 19.3 |
| Polyethylene | 7.8 | 9.3 | 9.1 | 11.4 | 11.4 | 12.1 | 8.1 | 10.1 | 15.6 | 15.9 |
| *P*-value | 0.2 | 0.07 | 0.1 | 0.3 | 0.1 | 0.01 | 0.1 | 0.01 | 0.2 | 0.01 |
| Contrasts[2] | | | | | | | | | | |
| NM versus HM | | | | | | NS | | NS | | ** |
| HM versus PE | | | | | | ** | | ** | | ** |
| Among HM | | | | | | NS | | ** | | NS |
| | | | | | **Gainesville** | | | | | |
| No mulch | 10.4 | 10.5 | 7.8 | 7.0 | 1.3 | 5.3 | 2.0 | 8.0 | 11.6 | 11.3 |
| HM1 | 11.2 | 11.0 | 7.1 | 6.5 | 5.0 | 5.8 | 3.6 | 8.3 | 10.2 | 10.3 |
| HM2 | 10.7 | 10.9 | 6.5 | 6.6 | 3.5 | 5.6 | 2.8 | 8.1 | 10.3 | 10.6 |
| HM3 | 10.3 | 10.4 | 7.8 | 7.1 | 4.6 | 6.1 | 1.4 | 8.8 | 10.9 | 11.0 |
| Polyethylene | 9.5 | 8.9 | 8.5 | 6.9 | 8.1 | 8.0 | 4.3 | 7.9 | 9.5 | 9.6 |
| *P*-value | 0.03 | 0.04 | 0.01 | 0.7 | 0.01 | 0.01 | 0.01 | 0.9 | 0.02 | 0.04 |
| Contrasts | | | | | | | | | | |
| NM versus HM | NS | NS | NS | | ** | NS | NS | | * | * |
| HM versus PE | ** | ** | ** | | ** | ** | ** | | * | * |
| Among HM | NS | NS | NS | | NS | NS | ** | | NS | NS |

[1] Sample dates 1, 2, 3, 4 and 5 correspond to 2 March, 15 March, 30 March, 13 April and 26 April in Loxahatchee; and 28 March, 12 April, 23 April, 7 May and 20 May in Gainesville.

[2] NM, HM and PE are no mulch, hydramulch and polyethylene mulch, respectively. Contrasts are designated NS when nonsignificant. * and ** indicate significance at 0.05 and 0.01 levels, respectively. Contrasts were not used when ANOVA indicated no significant difference among treatment means.

the beds. This may be explained by the relatively high permeability of the hydramulch. In Gainesville, the soil moisture in hydramulch beds was consistently 1–4% lower than in polyethylene-mulched beds during periods without rainfall. The rains that occurred during the final week of March and around 20 May resulted in higher moisture with hydramulch relative to polyethylene. Overall, it can be concluded that no practical differences exist among hydramulches as statistical difference in soil moisture among hydramulch treatments occurred on only one measurement date at each location.

Drip irrigation was used to promote weed germination and growth and to assess the effects of soil moisture on hydramulch integrity under soil moisture conditions that could be expected if a crop were present. The use of irrigation masked possible differences in soil moisture content that can occur between nonmulched and mulched soils. However, previous work has demonstrated the effectiveness of natural mulches in conserving soil moisture. In an experiment in which no irrigation was used, by 4 weeks after treatment, shredded newspaper, chopped newspaper and synthetic mulches all had higher soil moisture than the nonmulched control[27]. With nonbonded or loose materials such as shredded newspaper, the depth of the mulching material can be critical[27] and may explain why effects on soil moisture are not always consistent[22,28]. Higher soil moisture content with natural mulches has been attributed to increased infiltration of rainfall, whereas polyethylene mulch can limit the contribution of rainfall and overhead irrigation[13]. The permeability of hydramulch to rainfall and overhead irrigation would allow faster watering of beds with less water than polyethylene mulches and would be useful where drip irrigation is unavailable.

## Weed biomass

The comparative effect of the mulches on weed biomass was evaluated 11.5 and 12 weeks after mulch application at Loxahatchee and Gainesville, respectively. No difference in biomass was apparent among the hydramulch treatments at either location (Table 3). At Loxahatchee, weed biomass with hydramulch was less than with the nonmulched control but greater than with polyethylene. Fresh and dry

**Table 3.** Effect of mulch type on weed biomass 80 and 83 days after mulch application in Loxahatchee and Gainesville.

| | Loxahatchee | | Gainesville | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | Nutsedge | | Grasses | | Broadleaf | | Total | |
| | FW | DW | FW | DW | FW | DW | FW | DW | FW | DW |
| | g m$^{-2}$ | | | | | | | | | |
| No mulch | 2512 | 467 | 129 | 39 | 848 | 172 | 878 | 224 | 1855 | 435 |
| HM1 | 1281 | 254 | 172 | 47 | 413 | 75 | 0 | 0 | 585 | 123 |
| HM2 | 1208 | 248 | 164 | 49 | 581 | 112 | 73 | 22 | 818 | 183 |
| HM3 | 870 | 172 | 142 | 39 | 331 | 61 | 344 | 86 | 818 | 186 |
| Polyethylene | 90 | 14 | 90 | 22 | 0 | 0 | 0 | 0 | 90 | 22 |
| Significance | 0.0001 | 0.0001 | 0.84 | 0.79 | 0.16 | 0.18 | 0.05 | 0.07 | 0.02 | 0.02 |
| Contrasts | | | | | | | | | | |
| NM versus HM[1] | ** | ** | | | | | ** | | ** | ** |
| HM versus PE | ** | ** | | | | | NS | | NS | NS |
| Among HM | NS | NS | | | | | NS | | NS | NS |

[1] NM, HM and PE are no mulch, hydramulch and polyethylene mulch, respectively. Contrasts are designated NS when nonsignificant. * and ** indicate significance at 0.05 and 0.01 levels, respectively. Contrasts were not used when ANOVA indicated no significant difference among treatment means.

weed biomass were more than two times greater in the nonmulched control than the hydramulch treatments, and 12-fold more fresh weed biomass and 16-fold more dry biomass occurred in the hydramulch treatments than with the polyethylene treatment. In Gainesville, fresh and dry biomass of nutsedge and grasses with hydramulch and polyethylene were statistically similar. Broadleaf weeds, which grew to over 1 m high in the nonmulched control beds, resulted in greater fresh biomass in the nonmulched control than those broadleaf weeds that grew through cracks in hydramulch beds. No broadleaf weeds and grasses occurred within the polyethylene mulch treatment.

### *Weed counts*

**Loxahatchee.** Weed density was assessed 13, 26, 41, 56 and 69 days after mulch application. Nutsedge populations were low at this location and density was similar in all treatments (Table 4). In contrast, more grasses and broadleaf weeds were present with the nonmulched control than with hydramulch treatments throughout the field trial. Through day 41, differences in density of broadleaf weeds and grasses between hydramulch and polyethylene, and among hydramulch treatments were not significant. However, by day 56, broadleaf weeds emerged through cracks in the hydramulch, resulting in higher population densities compared to polyethylene. Nutsedge pressure was minimal, with no difference in nutsedge populations between polyethylene and hydramulch.

**Gainesville.** Weed densities were assessed on day 8, 26 and 44 after mulch application. Purple nutsedge was the predominant weed in all treatments (Table 4), with more nutsedge in the hydramulch treatments (up to 11 times more) compared with polyethylene by day 26. The density of nutsedge leveled off after the first month, which was likely due to the added mulch effect from a thick blanket of non-penetrating nutsedge leaves trapped beneath the hydramulch, and forcing the hydramulch upwards 4–8 cm in some places. By day 44, nutsedge that had penetrated the hydramulch was 6–9 cm in height and dense enough to shield approximately 50% of the hydramulch from sunlight. Broadleaf weeds in the nonmulched control increased over time so that by day 44, broadleaf weed density in the nonmulched control was significantly higher than in the hydramulch treatments.

These results show that broadleaf and grass weed densities with the hydramulch treatments were generally lower than the bare ground control and the suppression of broadleaf and grass weeds by hydramulch and polyethylene mulch was similar. However, hydramulch was readily penetrated by purple nutsedge, especially at the Gainesville site where high nutsedge populations existed. Nutsedge is less able to penetrate polyethylene mulches that transmit light than opaque polyethylene films[11,12]. Dense populations of nutsedge were observed growing under the hydramulch and lifting it several centimeters off the bed surface. Leaf expansion and growth under the hydramulch appeared to occur after widespread nutsedge penetration and growth had lifted the hydramulch. This is consistent with the study by Chase et al.[11], who found that nutsedge penetrated polyethylene mulch more readily where the mulch was applied tightly against the soil, but considerably less penetration occurred with a small space between the soil and the mulch. No single hydramulch treatment proved more effective in suppressing nutsedge (and other weeds) than the other hydramulch treatments at either research site; therefore increased amounts of gypsum and newsprint did not produce a mulch product with improved suppression capacity.

In contrast to the findings of Liburd et al.[17], who reported that the moist, softened 'hydromulch' was easily penetrated by weeds, increased moisture in the hydramulch did not

**Table 4.** Effect of mulch types on weed population densities (plants $m^{-2}$) of broadleaf weeds (B), grasses (G), and nutsedge (N) in Loxahatchee and Gainesville.

| Mulch treatments | Sample dates[1] | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | | 2 | | | 3 | | | 4 | | | 5 | | |
| | B | G | N | B | G | N | B | G | N | B | G | N | B | G | N |
| | Loxahatchee | | | | | | | | | | | | | | |
| | Plants $m^{-2}$ | | | | | | | | | | | | | | |
| No mulch | 53 | 128 | 3 | 235 | 172 | 9 | 29 | 20 | 1 | 42 | 27 | 0 | 30 | 15 | 2 |
| HM1 | 19 | 0 | 3 | 27 | 3 | 7 | 5 | 0 | 3 | 12 | 1 | 2 | 15 | 3 | 4 |
| HM2 | 3 | 0 | 2 | 20 | 9 | 4 | 4 | 2 | 2 | 13 | 4 | 4 | 17 | 7 | 3 |
| HM3 | 13 | 0 | 3 | 23 | 2 | 7 | 6 | 1 | 3 | 20 | 2 | 1 | 20 | 6 | 2 |
| Polyethylene | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *P*-value | 0.01 | 0.04 | 0.3 | 0.01 | 0.01 | 0.2 | 0.01 | 0.01 | 0.4 | 0.01 | 0.01 | 0.1 | 0.01 | 0.01 | 0.7 |
| Contrasts[2] | | | | | | | | | | | | | | | |
| NM versus HM | ** | ** | | ** | ** | | ** | ** | | ** | ** | | * | ** | |
| HM versus PE | NS | NS | | NS | NS | | NS | NS | | ** | NS | | ** | * | |
| Among HM | NS | NS | | NS | NS | | NS | NS | | NS | NS | | NS | NS | |
| | Gainesville | | | | | | | | | | | | | | |
| No mulch | 0 | 59 | 148 | 57 | 49 | 284 | 59 | 18 | 252 | | | | | | |
| HM1 | 0 | 3 | 111 | 3 | 7 | 230 | 0 | 5 | 149 | | | | | | |
| HM2 | 0 | 0 | 215 | 0 | 0 | 300 | 0 | 2 | 249 | | | | | | |
| HM3 | 0 | 0 | 100 | 4 | 5 | 210 | 3 | 2 | 162 | | | | | | |
| Polyethylene | 0 | 0 | 46 | 0 | 0 | 21 | 0 | 0 | 26 | | | | | | |
| *P*-value | 1 | 0.1 | 0.2 | 0.4 | 0.4 | 0.03 | 0.03 | 0.1 | 0.3 | | | | | | |
| Contrasts | | | | | | | | | | | | | | | |
| NM versus HM | | | | | | NS | ** | | | | | | | | |
| HM versus PE | | | | | | ** | NS | | | | | | | | |
| Among HM | | | | | | NS | NS | | | | | | | | |

[1] Sample dates 1, 2, 3, 4 and 5 at Loxahatchee correspond to weed counts performed 13, 26, 41, 56 and 69 days, and sample dates 1, 2 and 3 in Gainesville were done 8, 26 and 44 days, after mulch application.
[2] NM, HM and PE are no mulch, hydramulch and polyethylene mulch, respectively. Contrasts are designated NS when nonsignificant. * and ** indicate significance at 0.05 and 0.01 levels, respectively. Contrasts were not used when ANOVA indicated no significant difference among treatment means.

appear to lead to greater weed penetration. The drip emitters regularly moistened the hydramulch up to a 10 cm radius with no observable increase in weed penetration near the emitters—an important finding when considering using hydramulch in wet weather conditions or with overhead sprinklers. The results with foam mulch[16] suggest that a thicker material that maintains its integrity throughout the season is highly effective at suppressing broadleaf weeds.

In conclusion, a paper-like mulch that is applied as a slurry precludes the need for embedding of edges in the soil, which leads to the disintegration of standard kraft paper mulch. Hydramulch is fully biodegradable and so does not have the adverse environmental impacts of polyethylene film. All three formulations of hydramulch tested performed in a similar manner to suppress broadleaf and grass weeds to lower levels than a bare ground control and generally equivalent to polyethylene mulch. Since soil temperatures were 1–4°C cooler than under polyethylene, hydramulch may be more applicable for fall crops. Hydramulch should be used at a minimum thickness of 4 mm to ensure season-long durability and high nutsedge infestations should be avoided or controlled by alternative means. Future research with hydramulch should focus on mulch thickness, adhesion to soil, addition of color to promote warming, and improved method of application.

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# The Huitlacoche Project: A tale of smut and gold

Lydia Zepeda*

Department of Consumer Science, University of Wisconsin-Madison, 1300 Linden Dr., Madison, WI 53706, USA.
*Corresponding author: Lzepeda@wisc.edu

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## Abstract

This is a tale, over 500 years in the making, of how a university–community farm collaborative research project turned corn smut into gold.

**Key words:** CSA, huitlacoche, university–community collaboration

Huitlacoche (wheat-la-coach-ay) is commonly called corn smut in the US. Corn farmers know it for the economic damage it inflicts. The Aztecs saw huitlacoche in a different light: as a culinary delicacy. Gourmets around the world are beginning to catch on.

Since 'discovering' huitlacoche nearly 500 years ago, Western scientists have tried to find ways to eradicate it and to prove that *Ustilago maydis*, the fungus responsible, is harmful. The only effective means to control the fungus is to select varieties of maize that are not susceptible. *U. maydis* thwarted scientists by being irritatingly nutritious and stubbornly non-toxic; however, the fungicides developed to eradicate it did prove to be deadly to humans.

## A University–community Partnership

To encourage cooperation between universities and community organizations, the W.K. Kellogg Foundation sponsored a project that is a collaboration between the University of Wisconsin-Madison (UW) and the newly formed Friends of Troy Gardens (FTG). FTG is a non-profit organization dedicated to the development, management and stewardship of 10.5 ha of open space site in Madison, WI, USA. The purpose of the project was to develop the site, strengthen the FTG organization, and establish educational programs for the community. The UW faculty and graduate students involved in the project are conducting research and outreach to help improve the agronomic and economic sustainability of Troy Community Farm and the social sustainability of FTG. UW students also have the opportunity for agricultural internships with FTG and faculty use the site for demonstration of community projects, natural areas management and agricultural practices.

The land includes community gardens; a kids' garden; handicapped-accessible gardens; woodland and prairie restoration; nature trails; and edible landscaping to provide the community with open space, access to fresh produce and educational opportunities. In addition, there is an organic, urban farm to provide financial support for FTG as well as access to fresh local produce for those not able to garden. On 2 ha adjoining the site, the Community Land Trust is building 24–30 units of affordable co-housing.

## A University–community Farm Research Partnership

Established in 2001 as Madison's first and only urban farm, Troy Community Farm occupies 2 ha of the FTG site and is certified organic. The farm is organized as a community-supported agriculture (CSA) enterprise. In order to reach a wider community, the farm also sells at a farm stand on site and at two farmers' markets. CSA members receive fresh, organic produce from the farm each week for 21 weeks from June through October. To make membership accessible, members can pay in installments; low-income households can receive subsidized shares; and can exchange their labor for membership (worker-shares). In addition, the farm has adopted a strategy of selling a small range of profitable crops wholesale to keep CSA membership fees low.

The Huitlacoche Project is a specific project of the UW–FTG partnership to promote the agronomic and economic sustainability of the Troy Community Farm as well as reach out to the Hispanic community[1]. UW faculty

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and students are conducting research and outreach in cooperation with FTG staff and volunteers to improve the agronomic, economic and social sustainability of Troy Community Farm. FTG and the farmer set the research objectives. One objective was to identify a profitable crop that could be sold wholesale to keep the cost of CSA membership low. This pointed to a strategy to identify high-value and preferably perishable crops. The latter would give a comparative advantage to local production. Another objective was to identify crops that would create ties with ethnic communities. FTG already had a large number of Southeast Asians involved in the community gardens (over 60% of the gardeners are in fact Southeast Asians), but at the start of the project, no Hispanics and very few African-Americans. Several crops were discussed that might simultaneously meet the criteria of high-value, perishable and ethnic appeal. Huitlacoche fit the bill.

## What is Huitlacoche?

Huitlacoche was first described in 1575 by Bernardo Sahagun, a European, in his book *Earthly Things*, an amazing catalog of new world animal and plant species, complete with drawings by indigenous artists, and descriptions in Nahuatl and Spanish[2]. His description of huitlacoche reveals that he saw it through European eyes, as a blight on a far more interesting crop, maize. The Spaniards immediately saw the economic potential of maize, a grain that dwarfed their own crops. The literal translation of the roots of the word (excrement, to sleep) did nothing to disrupt this European perspective. Though, had Sahagun reflected on the roots of the Nahuatl words for silver and gold, divine and yellow excrement, he might have enquired more carefully about huitlacoche. And in light of the bearded foreigners' reaction to divine and yellow excrement, the indigenous informants had every incentive to say as little as possible. (As examples of different cultural perspectives, the Aztecs viewed excrement as a valuable fertilizer. They also bathed frequently and tried, but failed, to introduce the custom to the Spanish conquistadors).

What is clear is that the indigenous peoples of Central Mexico viewed huitlacoche as a highly valuable delicacy, and that it continues to be highly esteemed in Mexican cuisine. As a testament to the persistence of cultural biases, nearly 500 years after the conquest of the Aztecs, huitlacoche is just beginning to be recognized outside Mexico as a gourmet food. It has been featured in gourmet restaurants and magazines. And it also has the characteristics we were looking for in our project: high-value, perishable, and part of Mexican culture and cuisine.

## Learning to Propagate Huitlacoche

Identifying a potential crop was the first step. However, we needed to know how to grow and market it. Huitlacoche occurs naturally. The fungus *U. maydis* is endemic in the soil wherever maize is grown. The fungus can become airborne and lands on the plants' silks, entering the kernels. The kernels swell as they fill with the black fungus, changing color from pale yellow to silver and eventually to black. If not harvested, the galls will burst and spores return to the soil.

Marketing naturally occurring corn smut is an unreliable prospect; we needed to learn how to propagate huitlacoche. Agronomy professor Bill Tracy, an expert on sweet corn at the UW, and his graduate student Camilla Vargas conducted research on how to propagate huitlacoche by reversing what they knew about preventing corn smut. They picked varieties of maize that are susceptible and developed a planting schedule to extend the season for huitlacoche[3,4]. To propagate huitlacoche, *U. maydis* was replicated in a laboratory to create inoculum that could be sprayed in young corn when the silks emerge[5]. 2005 was the third year of field trials and the second year that Troy Community Farm has been able to sell huitlacoche commercially.

## Using Outreach Events to do Research: What Chefs Wanted

Initially, the FTG staff identified high-end restaurants that featured local food, as their desired market for all their farm's products. The staff's own reaction to huitlacoche itself was, at best, tepid. Enthusiasm began to sprout as they saw the response at the events and cooking demonstrations organized to facilitate market research. Participants were interviewed in English or Spanish to gather information about interest in huitlacoche, willingness to pay and familiarity with Troy Gardens. In addition to market research, the events served as outreach activities to the community, particularly the Hispanic community. Marketing research was also conducted by interviewing restaurant and grocery store owners and chefs. I was also responsible for post-harvest research on care and processing of huitlacoche. Several graduate students have assisted me over the past 3 years: Kathy Gonzalez, Kym Leggett, Martin Hernandez and Willow Russell.

A local chef, Robert Hughes, who was familiar with huitlacoche, was enlisted to conduct the first demonstration. Chefs from several high-end restaurants were invited to watch the preparations and taste the results. They were also given samples of fresh huitlacoche to feature in their restaurants. In exchange they agreed to be interviewed.

The chefs proved to be more enthusiastic about huitlacoche than their Anglo customers who were unfamiliar with it and generally inclined to make conventional choices when dining out. The chefs said they would be interested in buying, at most, a few pounds a week. The quantities would not justify the cost of the farmer's time to make the deliveries. Nor did the huitlacoche prove to be an entrée to buying other produce from Troy Community Farm. The owner-chefs who featured local food all responded in kind that they had a long-standing relationship with a local farmer and would not violate that relationship

by buying anyone else's produce. The other chefs worked for restaurants that did one-stop shopping with a supplier and viewed it as an inconvenience to buy produce piecemeal.

The interviews also revealed that the chefs wanted fresh huitlacoche 'cleaned' off the cob and ready to use. Post-harvest research revealed that cleaned huitlacoche would not keep more than a few days. On the cob, with certain procedures, it could be stored for a week to 10 days. Freezing was considered, but required special facilities and licensing.

## Using Events to do Market Research on What the Public Wanted

To gather information about the retail market, a second cooking demonstration at a local Mexican grocery featured three Mexican cooks who made traditional dishes: tacos, tostadas and quesadillas. Publicity was targeted to the Anglo and Hispanic community. Over 100 people came and were enthusiastic. Another demonstration was conducted in 2003 at a food festival with five cooks who prepared traditional Mexican and fusion dishes. Over 300 food samples were served. Surveys at both events revealed very positive responses. However, the Anglo market for huitlacoche appeared to be quite small, not merely because they were not familiar with it, but because they cooked from scratch so infrequently. Those willing to pay for huitlacoche were the people most familiar with it, though also with the least income: the Mexican community.

In 2004, the second season of research, the results of the propagation research yielded a more reliable and abundant crop. The marketing outreach included participating in a local Hispanic festival, organizing a huitlacoche festival in cooperation with a Mexican grocery, and another cooking demonstration at a local food festival. The huitlacoche festival featured food samples, food for sale, music, and piñatas. Local TV and newspaper media covered the event, while graduate students surveyed some of the over 200 participants.

The lessons of the first year pointed to focusing the second year of marketing research on Mexican groceries and restaurants. They were familiar with the product and demanded sufficient quantity to make deliveries worthwhile. However, even the Mexican restaurants wanted it cleaned. Because the product is perishable, it became clear that some sort of preservation would facilitate marketing and freezing that was the best option. Canned huitlacoche was available, but a very inferior product and should not be substituted for fresh or frozen huitlacoche.

In year 3, 2005, the outreach efforts were focused on a single event: a huitlacoche festival as part of the summer FTG event at Troy Gardens. Over 700 people showed up, to listen to music, hit piñatas, taste samples of huitlacoche, and buy huitlacoche prepared by food vendors. Four local TV stations and other reporters covered the event.

One of the unexpected results of the marketing research was that Mexicans familiar with huitlacoche found the propagated huitlacoche odd looking. The inoculated corn developed huitlacoche galls in many of the kernels, giving propagated huitlacoche a much different look than 'wild' huitlacoche. Propagated galls tend to be smaller, more uniform, and there are many more of them.

## Final Lessons Learned

The marketing and agronomic research indicated that frozen huitlacoche is the best option for the Community Farm; propagation of huitlacoche could be consolidated to only two plantings each of two varieties of corn. This has the added benefit of reducing labor requirements, a limited resource on the Community Farm.

Land for the urban Community Farm is fixed at 2 ha and sweet corn is not included in the crops grown because land is so scarce. However, fresh huitlacoche can be sold for 30–40 times the value of sweet corn, justifying use of scarce land. Because demand for huitlacoche was found to be inelastic and the fresh crop is very perishable, the best strategy for the Community Farm is to sell fresh huitlacoche at the farm stand and farmers' markets and to sell frozen huitlacoche wholesale. Freezing allows larger volumes to be sold in a single delivery, bringing back the potential of profitable sales to high-end restaurants, the original goal of community organization.

In the end, university researchers working with an urban farm rediscovered what was known 500 years ago; that the real wealth of the Aztecs was always agriculture. For gold can be spent or stolen, while agriculture can make gold.

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# The influence of organic transition systems on beneficial ground-dwelling arthropods and predation of insects and weed seeds

Jonathan G. Lundgren[1,*], John T. Shaw, Edmond R. Zaborski, and Catherine E. Eastman

Center for Ecological Entomology, Illinois Natural History Survey, 1618 South Oak Street, Champaign, IL 61820, USA.
*Corresponding author: jlundgren@ngirl.ars.usda.gov

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## Abstract

The influence of farm management practices on ground-dwelling natural enemy communities and predation of insects and weed seeds was investigated over the first 2 years of the transition from conventional to organic production. Three transition strategies were selected that differed in their management and input intensities, and were characteristic of pasture/ley systems (low intensity), cash grain systems (intermediate intensity), and vegetable production (high intensity). Beneficial arthropods (insectivores and granivores) were monitored using pitfall (arthropod activity) and quadrat (arthropod density) samples. The frequency of predation on restrained larvae of *Galleria mellonella* and the species observed feeding were recorded. Weekly removal rates of weed seeds representative of abundant species at our site were monitored over a 3-week period during fall. Management intensity affected the activity and abundance of biological control agents. In year two of the transition, biological control agent densities were higher in the low-intensity treatment than in the other two treatments, but activity of insectivores and granivores was reduced in this treatment relative to the higher intensity systems. The patterns in the abundances of biological control agents may be explained by habitat stability within the different cropping systems. Quadrat samples were strongly correlated with the insectivory index, although pitfall samples were not. Insectivory rates were highest (>80% of *G. mellonella* larvae) in the low-intensity treatment. Predation patterns over a 17-h period differed substantially among the management treatments, indicating behaviorally distinct insectivore communities. Seed removal was also highest in the low-intensity treatment. We conclude that low-intensity cropping systems are most favorable to the abundance and function of beneficial ground-dwelling arthropod communities (insectivores and granivores) during the transition process.

**Key words:** Araneae, Carabidae, granivore, Gryllidae, organic, predator, transition

## Introduction

Farmers in the US approach the 3-year transition from conventional to organic production using different strategies that have variable effects on the biological control of insect and weed pests. Some of the adjustments to farming necessary during this transition period are in the tools that are used for organic versus conventional crop production. Examples of these tools include improving soil fertility through incorporating organic matter into the soil versus applying inorganic fertilizers, using biologically and culturally based pest management options versus synthetic chemicals, and planting polycultures versus monocultures. The degree to which these different tactics are implemented profitably is characteristic of the management intensity of the system.

The types and intensities of cropping practices have important implications for soil fauna. Ground-dwelling

[1]Current address: Northern Grain Insects Research Laboratory, USDA-ARS, 2923 Medary Avenue, Brookings, SD 57006, USA.

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granivore and insectivore communities, represented in part by ground beetles (Coleoptera: Carabidae), often are reflective of certain management systems and practices[1–3]. Certain species of ground beetles are strongly associated with organic or conventional farming systems[4]. Within these systems, specific farming practices such as weed and ground cover management[5,6], insecticide application[7,8], cultivation timing and frequency[7,9,10], soil amendments such as manure or mulch[6,11,12], and crop selection[13,14] all influence the communities of ground beetles and other beneficial arthropods. Thus, different cropping systems and farming practices are inherently different in their compatibility with biological control of pests, or the use of beneficial insects (and other organisms) as agents of pest management.

Although it is commonly understood that beneficial insects are impacted by farm management, the effects of specific farm management practices on their function as biological control agents is less understood. Nevertheless, instances of management practices that influence biological control have been reported. Brust et al.[7,15] associated deep cultivation with decreases in predation rates of the black cutworm, *Agrotis ipsilon* (Hufnagel) (Lepidoptera: Noctuidae), and found that predator abundance was negatively correlated with plant damage by *A. ipsilon*. Reichert and Bishop[12] showed that mulching garden plots increased spider densities and decreased insect pest populations. Investigating biological control agents of weed seed banks, Cromar et al.[10] observed that tillage affected seed removal rates by granivorous insects. Also, crop type and cropping density affects the levels of seed consumption by arthropods[16].

Researchers at the Illinois Natural History Survey and University of Illinois initiated a field study in 2003 to compare the influence of organic transition schemes on weed populations, soil organic matter and fertility, soil invertebrates, and the relationship between soil fertility, plant health and insect/disease pressure. An advisory panel of Illinois organic producers assisted in the development of the study, which compares three dominant approaches to the transition process that vary in the class of crops planted, level of soil disturbance and amendments, number of inputs for pest management, and economic returns. The three systems selected take into account a farmer's history and income requirements during the transition process. The three transition systems represented in our experiment were: (1) high-intensity transition systems, which use costly inputs such as organically approved insecticides, hand-labor or weeding along with frequent tillage, and require high returns such as those from vegetable crops; (2) intermediate-intensity transition systems, such as cash-grain systems, which use fewer costly inputs and involve less soil disturbance while still generating some income; and (3) low-intensity transition systems that include few to no added inputs or pest management activities to produce a forage crop or fallow but provide minimal economic returns during the transition period. The systems were identified based on several informal phone conversations and listening sessions with organic producers in Illinois and at a workshop held at the Illinois Natural History Survey to identify key research needs of organic producers. The advisory panel reviewed the selection of treatments and agreed that they were representative of predominant pathways by which organic producers approach the transition process in our region.

Systems approaches are specifically designed to increase the relevancy of a research program, and while this approach does not identify specific mechanisms that are mitigating the level of beneficial arthropods and biological control in the different treatments, it does give us a 'real-world' picture of how some predominant methods for transitioning to organic production affect this important form of pest management. Here, we document how these different strategies for handling the transition to organic production influence the abundance and activity of ground-dwelling arthropod communities and the predation of insects and weed seed banks during the first 2 years of the transition process.

## Materials and Methods

### *Field site and management*

Research was conducted on the Cruse Farm of the University of Illinois in Champaign, IL (N 40.08, W 88.24) in 2003–2004. The transition to organic production was initiated in 2003 on a site that had been under conventional corn and soybean production through the 2002 growing season. Only certified organic seed (unless otherwise noted) and materials approved for the production of certified organic crops were used in managing the field site. In fall 2002, winter rye (*Secale cereale* L., 'FS Hi Rye 500', untreated non-organic seed, Growmark, Bloomington, IL, USA) was seeded (101 kg ha$^{-1}$) to use as a green manure and to reduce soil erosion. The rye was mown and incorporated into the soil by disking in spring 2003. Twelve experimental plots (30 m × 12 m) were established, and the three management-intensity treatments were randomly assigned to the plots in a randomized complete block design (RCBD) with four blocks. Plots were separated by alleyways (≥1.5 m wide) that were seeded with a mixture of meadow fescue (*Festuca pratensis* Ruds. 'Bartura') and smooth bromegrass (*Bromus inermis* L.) (untreated non-organic seed, Albert Lea Seed House, Albert Lea, MN, USA) and regularly mown.

**High-intensity treatment: vegetable system**

*2003: Tomatoes.* Six raised beds that ran the length of each plot were created with a bed-shaper (BP400 Super-bedder, Kennco Manufacturing, Inc., Ruskin, FL, USA). These beds were trapezoidal in cross-section, with the bottom dimension 0.91 m, 0.76 m at the top and 0.20 m tall. The beds were covered with embossed black plastic (Enviromulch™, Sonoco Products Company, Hartsville,

SC, USA). Tomatoes (*Lycopersicon esculentum* Miller 'La Rossa', grown from seed from Johnny's Selected Seed, Winslow, ME, USA) were hand transplanted into the raised beds between 30 May and 2 June. There were 1.8 m between rows and 0.46 m between plants within rows (approximately 400 plants per plot). To suppress weeds, wheat straw (not certified organic) was spread between the raised beds to a depth of 15 cm; adventive wheat populations originating from seeds in the straw persisted between raised beds throughout the season. Weeds (including volunteer wheat) were removed by hand or mowing before they could shed seeds. Plots in this treatment were not cultivated for weed control after tomatoes were planted, and no pesticides or fertilizers were applied. Tomatoes were harvested by hand between 28 August and 2 October (the date of the first killing frost), and many ripe tomatoes were left in the field. After removal of the plastic, the beds were leveled and the plant residues incorporated.

*2004: Cabbage and Broccoli.* In spring, plots were disked and Austrian winter peas (*Pisum sativum* L.; Seeds of Change, El Guique, NM, USA) inoculated with *Rhizobium leguminosarum* (Frank) were drilled into the plots at 190 kg ha$^{-1}$ as a green manure. These peas were mown and incorporated into the soil using an Imants (Reusel, The Netherlands) spading machine with power harrow. Cabbage (*Brassica oleraceae* L. 'Tendersweet') and broccoli (*B. oleraceae* L. 'Gypsy') (untreated non-organic seed, Johnny's Selected Seeds, Winslow, ME, USA) were transplanted on 16 July in alternating rows. Ten rows of crucifers were planted in each plot, with plant spacing of 0.91 m between and 0.4 m within rows. Spinosad (an insecticidal byproduct of *Saccharopolyspora spinosa*; Entrust® WP80, Greenfire Inc., Chico, CA, USA) was applied twice to suppress cruciferous Lepidoptera, based on periodic plant sampling and treatment guidelines adapted from Weinzierl and Cloyd[17]. The first application (69 g ai ha$^{-1}$) was made on 13 August using a two-row tractor-mounted boom with three hollow-cone nozzles per row. A second application (95 g ai ha$^{-1}$) was made on 11 September using a hand-pressurized backpack sprayer equipped with a hollow-cone nozzle. For both applications, Crocker's Fish Oil (Crocker's Fish Inc., Quincy, WA, USA) (2.6 ml liter$^{-1}$ water) was used as a sticker-spreader, to ensure good insecticide coverage on the plants. Weeds were controlled with a single row cultivator on 23 July and by hand between 2 and 9 September. Cabbage and broccoli were harvested for yield and quality assessment between 14 and 29 September.

**Intermediate-intensity treatment: cash grain system**

*2003: Soybeans.* On 2 June, the plots assigned to this treatment were planted with soybeans (*Glycine max* (L.) Merr. 'Vinton', Ridgeline Farm, Cerro Gordo, IL, USA). Soybeans were planted in 16 rows that were separated by 0.76 m, and the seeding rate was 420,000 seeds ha$^{-1}$. No pesticide applications were made. To manage weeds, the soybeans were cultivated with a single row cultivator on 18 June and 15 July. Soybeans were harvested on 9 October, when beans had dried on the plant to approximately 12% moisture, as determined with a Farmex® MT# moisture meter (Farmex Electronics, Streetsboro, OH, USA). Winter wheat (*Triticum aestivum* L., Gleason Grains, Bridport, VT, USA) was drilled (134 kg ha$^{-1}$) on 21 October.

*2004: Wheat.* Weeds and insects were not managed in the winter wheat. Wheat was harvested on 28 June. Straw was raked, baled and removed in early July. Wheat stubble and weeds were mown on 12 August. Otherwise, the plots were left fallow until 9 September, when hairy vetch (*Vicia villosa* Roth, Albert Lea Seed House, Albert Lea, MN, USA) was drilled into the wheat stubble at 48 kg ha$^{-1}$ as a green manure cover crop.

**Low-intensity treatment: pasture system**

*2003 & 2004: Hay/Pasture.* On 2 June, the plots assigned to the low-intensity treatment were planted with a hay and pasture mix (22 kg ha$^{-1}$, Hay/Pasture Mix 1, untreated non-organic seed, Albert Lea Seed House, Albert Lea, MN, USA). This mixture contained the following forages (percentage of mixture): alfalfa (*Medicago sativa* L. var. 'Big Sky'; 29.5%), red clover (*Trifolium pratense* L. var. 'Arlington'; 19.9%), timothy (*Phleum pratense* L. var. 'Climax'; 19.9%), orchard grass (*Dactylis glomerata* L. var. 'Potomac'; 19.5%) and Alsike clover (*Trifolium hybridum* L.; 9.9%). To prevent the establishment of perennial weeds, these plots were mown to 15 cm on 15 July and 1 August, 2003. In 2004, the plots were mown on 30 April, 27 May, 22 June and 12 August.

## Arthropod activity

Pitfall-trap collections were made to determine possible effects of management-intensity treatments on the activity of ground-dwelling arthropods. A linear transect consisting of four pitfall traps[18] placed every 6.1 m was established down the center of each plot. The traps were filled with 100 ml of ethylene glycol as an insect preservative and were placed in the field for sampling periods of 5–8 days during several intervals over the 2003–2004 seasons. Sampling periods were always separated by at least 7 days. One sample was collected beginning 16 April, 2003, while cereal rye was present across the entire field, to establish that there were no pretreatment differences. In 2003, trapping periods were conducted beginning on 5 June, 19 June, 3 July, 22 July, 4 August and 9 September. In 2004, trapping periods were conducted beginning on 24 April, 4 May, 19 May, 2 June, 7 July, 24 July, 5 August, 25 August and 15 September.

Arthropods collected in the pitfall samples were sorted into categorical taxa: Carabidae (insectivores, granivores), Staphylinidae (insectivores), Gryllidae (insectivores, granivores, only in 2004), Coccinellidae (insectivores), Araneae (insectivores) and Phalangiidae (insectivores). Specimens of Carabidae, Gryllidae and Coccinellidae were identified to species, and other insectivores were identified to

morphospecies within a taxon (order or family). In general, the groups of arthropods highlighted here have a reputation as being beneficial; other species or groups may also be beneficial but are less well understood and so were not included in this study. Insectivore and granivore community data were analyzed separately. All four traps from a plot were consolidated into a single sample. Then the number of specimens per trap per day was calculated and compared among the three treatments using repeated measures ANOVA[19] ($n = 4$ plots for each sample period). Significantly different means were separated using the LSD test[19]. The numbers of catches were not compared between years because of seasonal differences in the trapping frequency and duration.

### Densities of beneficial arthropods

This experiment was conducted to determine the effect of management intensities on the actual densities of beneficial arthropods. Quadrat samples were used to determine differences in the actual densities of predators and granivores in the different management systems.

Two sample periods on 19–20 August 2004 were selected to represent day- and night-time densities of beneficial arthropods: from 9:00–14:00 and from 22:00–2:30 CST, respectively. Three random samples were collected in each plot in three of the blocks during each designated sample period. Specimens from the three random samples were then consolidated into a single sample for each plot (nine observations each during day and night). For each sample, a metal quadrat frame (0.25 $m^2$; 0.5 m × 0.5 m, 0.13 m tall) was randomly placed within a plot and pressed several centimeters into the ground. Vegetation was removed from within the quadrat and stored in a plastic bag until processing. Cabbage/broccoli plants within the quadrat were examined in the field and any beneficial arthropods on them were removed. All arthropods that occurred within the quadrat were removed with forceps or an aspirator and were stored until processing. Flashlights were used during the night sample to help locate arthropods. Vegetation samples were kept cool (approximately 10°C) until they could be placed into Berlese funnels (process described in Methven et al.[20]). Once the samples were completely dry, the vegetation was removed from the Berleses and examined to confirm that no arthropods remained in the vegetation.

The arthropods collected from the vegetation, soil, and detritus in the quadrat samples were identified to morphospecies and categorized as 'insectivorous', 'granivorous', 'both' or 'other'. Those classified as 'others' were discarded from the analyses. Comparisons of insectivore abundance among the management treatments and between the day and night periods were made with repeated-measures ANOVA. A similar analysis was used to compare granivore abundances. The mean numbers of specimens per plot within day and night samples were separated among treatments using Tukey HSD tests[19].

### Predation estimates

An index of predation on lepidopteran larvae (i.e. caterpillars) was generated for the different management intensities. Brust et al.[15] determined that ground-dwelling insectivores do not distinguish between lepidopteran species as long as they are of consistent size, and so wax moth (*Galleria mellonella* L. [Lepidopera: Pyralidae]) larvae were used as a surrogate prey. Observations of predation on restrained *G. mellonella* larvae were made on 22 September, 2004. Three ~3.5 h observation periods were selected: approximately 9:00–12:30 (morning), 13:00–16:30 (afternoon), and 22:30–2:00 (23 September) (night). For each time period, five observation sites were established at random locations within each plot; the same locations were used for all three periods. At each observation site, two late-instar *G. mellonella* (mean ± SEM weight was 0.23 ± 0.0064 g) were restrained to a 30 × 15 × 2-$mm^3$ piece of modeling clay (Polyform Products Co., Inc. Elk Grove Village, IL, USA) using insect pins (size 3) inserted through the posterior segment of their abdomens (as described by Frank and Shrewsbury[21]). In preliminary tests, larvae restrained in this manner survived for more than 24 h in the laboratory. To exclude vertebrate predators, each observation site was enclosed within an open-topped, cylindrical wire cage (8 cm tall and 7 cm in diameter, mesh size 1.2 cm) that was pressed 1–2 cm into the soil. A piece of vegetation was loosely placed over the prey to keep them from desiccating during the day. At the end of each observation period, the larvae were removed from the field and examined for signs of predation. Also, any insectivores that were found within the caged location at the end of the period were identified by sight and were released within the vicinity of the cage. The proportion of the ten prey larvae consumed per plot and the number of predation events in each plot by each insectivore species were recorded. The percentages of prey consumed in each management-intensity treatment and during each sample period were compared using repeated-measures ANOVA. Means were separated among management treatments and within treatments over the 17-h period using LSD comparisons.

### Granivory estimates

Weekly seed removal rates were used as an index of biological control of weed seed banks. Weeds encountered at our site (J.B. Masiunas, unpublished data) were lambsquarter (*Chenopodium album* L.), velvetleaf (*Abutilon theophrasti* Medic.), redroot pigweed (*Amaranthus retroflexus* L.), ivyleaf morning glory (*Ipomoea hederacea* [L.] Jacq.), crabgrass (*Digitaria sanguinalis* [L.] Scop.), giant ragweed (*Ambrosia trifida* L.) and giant foxtail (*Setaria faberi* Herrmann). Seeds of these species were ordered from commercial sources (Valley Seed Service, Fresno, CA, USA or V & J Seed Farms, Woodstock, IL, USA), and their identities were verified by germinating

them in the greenhouse and identifying the plant by morphology. Seeds of each species were affixed to the bottom halves of Petri dishes (15 cm diameter, 1 cm deep) with double-sided Scotch® tape (3M, St Paul, MN, USA). Each dish contained all of the species; seed numbers were 50 for *C. album*, *Ab. theophrasti*, *Ama. retroflexus*, *D. sanguinalis*, and *S. faberi* and 25 for the comparatively larger seeds of *I. hederacea* and *Amb. trifida*. Seed densities were comparable to or higher than respective seed populations commonly encountered in Midwestern agricultural fields[22,23]. In agricultural systems, seed removal rates tend to be density dependent at concentrations equal to or higher than field populations[23,24]. Three seed-containing dishes were placed in each of the plots at randomly selected sites. The dishes were buried so that their upper lips were flush with the soil surface, and surrounding soil and plant material were placed in and on the dish to mimic the surrounding vegetation and crop residue. An uncovered wire cage (1.4 cm × 1.4 cm mesh size, 15 cm diameter and 14.5 cm tall) was placed around each dish to exclude vertebrate granivores. To control for ancillary seed loss not attributable to granivory, we created dishes that contained black plastic beads and placed one dish in each plot. Large beads (approximately 4.2 mm diameter, 80 mg each; $n = 25$) and small beads (approximately 2.2 mm diameter, 10.5 mg; $n = 50$) were intended to generally represent the large and small weed seed species, respectively.

Seed removal rates were examined for three consecutive 7-day periods beginning on 6 September. Precipitation levels during the three 1-week intervals were recorded by the Illinois State Water Survey (http://www.sws.uiuc.edu/warm/data/) at a monitoring site 0.16 km to the north of the research plots. The seed removal sites remained fixed throughout the 3-week period. At the end of each week, the dishes with all of their contents were brought back into the laboratory and frozen at −10°C until processing. The contents of each dish were sifted through, and the number of each seed species or bead was recorded. Seeds which had their seed coat cracked were counted as removed. The numbers of seeds and beads missing were recorded for each plot over each 1-week period. The weekly removal rates were compared among treatments and sample weeks by repeated-measures ANOVA. Significantly different means among treatments and sample weeks were separated using LSD tests.

The number of each seed species consumed per plot was generated; data were pooled across management treatments and sample weeks ($n = 9$ dishes in each plot over 3 weeks). ANOVA was used to reveal any significant preferences for certain weed species. A Tukey HSD test was applied to separate significantly different means among the treatments. Each species was categorized as a grass or broadleaf species; ANOVA was used to determine preferences for broadleaves or grasses. The weight of ten seeds of each species was measured on 15 replicate groups using an electronic balance, and a general linear model was used to determine whether there was a relationship between seed biomass and average removal rate per week (removal rates were pooled over sample periods and treatments)[19].

### Sample methods and biological control indices

Pitfall and quadrat samples were correlated with the indices of insectivory and granivory to determine which sampling method was more representative of biological control by ground-dwelling arthropods during the latter part of the growing season. Quadrat samples to assess the densities of beneficial arthropods were collected on 20 August, 2004. The mean numbers of insectivores captured (per trap per plot per day) from traps that were in the field from 5 to 10 August represented the pitfall sample method. These sample dates were intended to give an indication of the relative populations of beneficial species during the latter part of the growing season. Granivory estimates spanned from 6 to 27 September, and insectivory rates were investigated on 22 September. A mean predation rate of wax moth larvae was derived from the morning, afternoon and night sample periods for each plot. Granivory was measured as the number of seeds removed per plot over the 3-week sample interval. Separate linear regressions were established for each of the insectivory and granivory indices and the two sample methods[19].

## Results

### Arthropod activity

A total of 3177 adult insectivores and granivores were collected in pitfall traps in 2003, and 2478 specimens were trapped in 2004 (Table 1). Management intensity significantly affected the total number of insectivores captured over the season in 2003 ($F_{2,9} = 7.98$, $P = 0.01$), but there were no significant differences in predator activity among the treatments in 2004 ($F_{2,9} = 2.37$, $P = 0.15$) (Fig. 1). In 2003, 69% of specimens collected in pitfall traps were the insectivorous species *Poecilus chalcites* (Say). This species was still the most commonly collected species in 2004, but comprised only 26% of specimens (Table 1).

Pitfall-trap data revealed an increase in the activity of granivorous species from 2003 to 2004, but management intensity did not influence granivorous communities. Granivorous ground beetles increased from 12.62% of total specimens (13 species) in 2003 to 36.67% of specimens (20 species) in 2004 (Table 1). Treatment did not affect the activity of the total granivores in 2003 (crickets weren't sampled in 2003) ($F_{2,9} = 1.65$, $P = 0.25$) or in 2004 (including crickets) ($F_{2,9} = 1.87$, $P = 0.21$).

### Densities of beneficial arthropods

A total of 465 predators, most of which were spiders, were collected from the quadrat samples (Table 2). Management

**Table 1.** Adult arthropod natural enemies captured in pitfall traps.

| Species | Granivorous (G) | % of 2003 specimens | % of 2004 specimens |
|---|---|---|---|
| Coleoptera: Carabidae | | | |
| *Agonum placidum* (Say) | G[33] | 0.03 | 0.08 |
| *Agonum punctiforme* (Say) | G[6] | 0.13 | 0.28 |
| *Agonum striatopunctatum* DeJean | G[4] | 0.03 | 0 |
| *Amara apricaria* (Paykull)[1] | G[33–35] | 0 | 0.08 |
| *Amara sinuosa* (Casey)[1] | G[4] | 0 | 0.40 |
| *Amphasia sericea* (Harris) | G[36] | 0 | 0.04 |
| *Anisodactylus carbonarius* (Say)[2] | G[4] | 0 | 0.04 |
| *Anisodactylus ovularis* (Casey)[2] | G[4] | 0.03 | 0 |
| *Anisodactylus rusticus* (Say)[2] | G[33,35,36] | 0 | 0.12 |
| *Anisodactylus sanctaecrucis* (Fabricius)[2] | G[36–38] | 1.76 | 10.65 |
| *Badister notatus* Haldeman | | 0 | 0.04 |
| *Chlaenius nemoralis* Say[3] | | 0 | 0.16 |
| *Chlaenius pusillus* Say[3] | | 0 | 0.08 |
| *Chlaenius tricolor* Dejean[3] | | 0 | 0.73 |
| *Cicindela punctulata* Olivier | | 0.22 | 0.12 |
| *Clivina bipustulata* (Fabricius) | G[4] | 0.91 | 0.04 |
| *Clivina impressefrons* LeConte | G[32,33,39] | 3.75 | 2.82 |
| *Colliuris pennsylvanica* (L.) | | 0 | 0.12 |
| *Cratacanthus dubius* (Palisot de Beauvois) | | 0.06 | 0.20 |
| *Cyclotrachelus seximpressus* (LeConte) | | 2.05 | 1.90 |
| *Harpalus caliginosus* (Fabricius)[2] | G[24,35,36] | 0 | 0.12 |
| *Harpalus compar* LeConte[2] | G[35] | 0.06 | 0.36 |
| *Harpalus fulgens* Csiki[2] | G[4] | 0 | 0.24 |
| *Harpalus herbivagus* Say[2] | G[36,40] | 0 | 2.78 |
| *Harpalus pensylvanicus* (DeGeer)[2] | G[24,37,41–43] | 3.37 | 11.18 |
| *Lebia analis* Dejean[3] | | 0 | 0.04 |
| *Patrobus longicornis* (Say) | | 0 | 0.16 |
| *Poecilus chalcites* (Say) | | 68.87 | 25.63 |
| *Poecilus lucublandus* (Say) | | 0.13 | 0.28 |
| *Pterostichus femoralis* (Kirby) | | 0.16 | 0.24 |
| *Pterostichus melanarius* (Illiger) | G[24,35,38,44] | 0.19 | 0.77 |
| *Scarites quadriceps* Chaudoir | | 0 | 0.04 |
| *Scarites subterraneus* Fabricius | | 0.03 | 0 |
| *Stenolophus comma* (Fabricius) | G[33,38,45] | 1.54 | 1.98 |
| *Stenolophus dissimilis* Dejean | G[4] | 0 | 0.08 |
| *Stenolophus lecontei* (Chaudoir) | G[33,35,45] | 0.63 | 0.32 |
| *Stenolophus ochropezus* (Say) | G[33] | 0.19 | 0.61 |
| *Trichotichnus autumnalis* Say | | 0 | 0.08 |
| Coleoptera: Coccinellidae | | | |
| *Coccinella septempunctata* L. | | 0.60 | 1.82 |
| *Coleomegilla maculata* DeGeer | | 0.06 | 2.14 |
| *Harmonia axyridis* (Pallas) | | 0.03 | 0 |
| *Hippodamia convergens* Guérin-Méneville | | 0 | 0.08 |
| *Scymnus* spp. | | 0 | 1.01 |
| Coleoptera: Staphylinidae | | | |
| Staphylinidae spp. | | 6.48 | 12.55 |
| Orthoptera: Gryllidae | | | |
| *Allonemobius fasciatus* (DeGeer) | G[4] | NA | 6.98 |
| *Gryllus pennsylvanicus* Burmeister | G[46] | NA | 3.03 |
| *Gryllus veletis* (Alexander) | G[5] | NA | 0.04 |
| Heteroptera: Nabidae | | | |
| *Nabis* sp. | | 0.13 | 0.40 |
| Arachnida: Araneae | | | |
| Lycosidae spp. | | 7.43 | 2.18 |
| Other spider spp. | | 0.28 | 0.56 |
| Opiliones: Phalangiidae | | | |
| Phalangiidae spp. | | 0.85 | 6.74 |
| Number of morphospecies | | 28 | 47 |

[1] Tooley and Brust[6] and Lindroth[39] suggest that this entire genus is granivorous to some degree.
[2] Tooley and Brust[6] declare that this entire genus is granivorous to some degree.
[3] Tooley and Brust[6] suggest that the entire genus is granivorous, but this is questionable. Brust and House[24] did see *Chlaenius* sp. and *Lebia* sp. visit seed trays in the field. However, Allen[34] and Larochelle[33] do not list any seeds in the diet of *Chlaenius* and *Lebia* spp. It may be that these species are granivorous, but more data are needed on the matter.
[4] No specific references to seed-feeding could be found for this species, although their close relationship with seed-feeding congeners makes it likely that they will feed on seeds to some degree.
[5] This is a close relative of *G. pennsylvanicus*, separable only based on seasonal phenology. Given its morphological similarity, we presume that this species is granivorous.
Collections totaled 3177 adult beneficial (granivore and insectivore) arthropods in 2003 and 2478 in 2004.

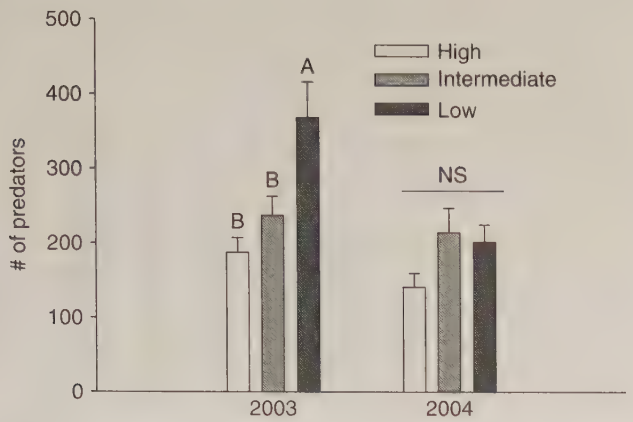


**Figure 1.** Mean (± SEM) insectivore activity in the different organic transition systems, as measured by pitfall samples ($n = 4$). Columns with different letters are significantly different from one another ($\alpha = 0.05$, LSD test).

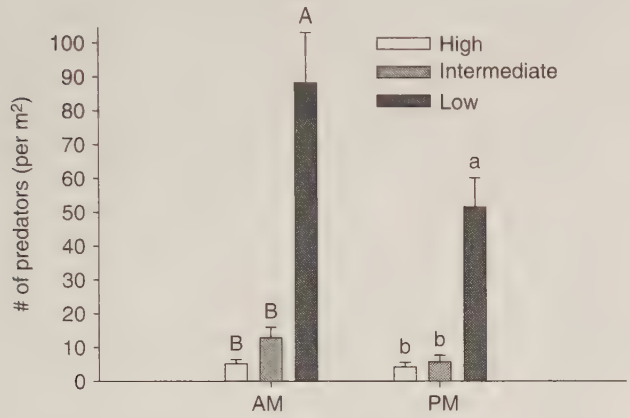


**Figure 2.** Mean (± SEM) densities of insectivorous arthropods collected from quadrat samples ($n = 3$ plots for each sample period/treatment combination). Bars within a sample period with different letters are significantly different (Tukey HSD test, $\alpha = 0.05$).

intensity had significant effects on the number of predators observed per plot ($F_{2,6} = 10.71$, $P = 0.01$) (Fig. 2), and sample period affected the number of insectivores encountered ($F_{1,6} = 7.82$, $P = 0.03$; treatment × sample period: $F_{2,6} = 4.77$, $P = 0.06$). Fewer predators were captured at night than during the day (Fig. 2). Averaging the mean day and night density estimates per $m^2$ extrapolated into approximately 45,000 (high), 100,000 (intermediate) and 733,000 (low) insectivores per hectare.

The 33 granivorous arthropods collected in the quadrat samples fell into four general taxa: Carabidae ($n = 11$; 5 spp.), *Gryllus pennsylvanicus* ($n = 9$), Miridae ($n = 9$) and Elateridae ($n = 4$). No granivores were found in the quadrat samples from the high-intensity plots. The density of granivores was significantly affected by management intensity ($F_{2,6} = 14.12$, $P = 0.005$), but sample period did not affect the number of granivores ($F_{1,6} = 5.45$, $P = 0.06$; treatment × sample period: $F_{2,6} = 10.10$, $P = 0.01$). The low-intensity treatment had the highest densities of granivores (mean ± SEMs were 0, $1.14 \pm 0.40$ and $5.14 \pm 1.24$ granivores per $m^2$ in the high-, intermediate- and low-intensity treatments, respectively).

**Table 2.** Abundance of individual predator taxa in quadrat samples.

| Predator taxon | Number captured |
|---|---|
| Araneae (spiders) | 257 |
| Hemiptera (includes adults and nymphs of Anthocoridae, Nabidae, Miridae, Pentatomidae and Geocoridae; true bugs) | 48 |
| *Chauleognathus* sp. larva (Coleoptera: Cantharidae; soldier beetles) | 43 |
| Chilopoda (centipedes) | 29 |
| Staphylinidae (adults; rove beetles) | 20 |
| Carabidae (adults; ground beetles) | 18 |
| Coccinellidae (adults and larvae; lady beetles) | 17 |
| Predatory mites (predatory families of Prostigmatidae and Mesostigmatidae) | 14 |
| *Gryllus pennsylvanicus* (field cricket) | 9 |
| Phalangiidae (harvestmen) | 9 |
| Thysanoptera: Aeolothripidae (predatory thrips) | 1 |
| Total | 465 |

Data were pooled over treatment and sample periods, a total of 63 samples (0.25 $m^2$ each).

## Predation in the field

The proportion of *G. mellonella* larvae consumed was significantly influenced by time of day and management intensity (treatment: $F_{2,9} = 6.97$, $P = 0.015$; sample period: $F_{2,18} = 9.72$, $P = 0.001$; treatment × sample period: $F_{4,18} = 3.95$, $P = 0.018$) (Table 3). A sharp increase in insectivory in the high-intensity plots during the night sample was responsible for the significant interaction observed here (Table 3).

A total of nine insectivorous morphospecies/taxa were found consuming *G. mellonella*. Larvae of *Chauleognathus* sp. (Coleoptera: Cantharidae) accounted for 70% of predation events (Table 4). Most predation occurred during the night; 71% of all events were observed at night, versus 16 and 13% during the morning and afternoon, respectively. Insectivory was most commonly observed in the low-intensity management system (55% of events, versus 22 and 14% in the high and intermediate systems, respectively).

## Granivory estimates

We recovered 97, 97 and 94% of the large beads and 99, 99 and 95% of the small beads that were placed in the high-, intermediate- and low-intensity treatments, respectively. Seeds (*C. album*, *Ama. retroflexus*, *D. sanguinalis* and *S. faberi*) were occasionally placed unintentionally into

**Table 3.** Predation rates of caterpillars (% of *G. mellonella* larvae consumed ± SEM) in the three organic transition systems ($n = 4$ plots for each sample period/treatment combination).

| | High | Intermediate | Low |
|---|---|---|---|
| Morning | 27.5 ± 4.8 Aa | 45.0 ± 17.1 Aab | 80.0 ± 10.8 Ab |
| Afternoon | 17.5 ± 8.5 Aa | 55.0 ± 1.5 Ab | 62.5 ± 9.5 Ab |
| Night | 75.0 ± 6.5 Bab | 55.0 ± 11.9 Aa | 87.5 ± 4.8 Ab |

Values within a column followed by different capital letters are significantly different within the treatment; values within a row followed by different lower-case letters are significantly different in predation among management systems for a particular sample period (LSD test, $\alpha = 0.05$).

**Table 4.** Predator taxa observed consuming caterpillars (*G. melonella* larvae) in the field.

| Species | Number of observations |
|---|---|
| *Chauleognathus* sp. larva (Col.: Cantharidae; soldier beetles) | 113 |
| Harvestmen (Opiliones: Phalangiidae) | 13 |
| *Poecilus chalcites* adult (ground beetle) | 11 |
| *Gryllus pennsylvanicus* (Orthoptera: Gryllidae; field cricket) | 10 |
| Centipede (Chilopoda sp.) | 8 |
| Slug (Mollusca: Gastropoda sp.) | 4 |
| Ground beetle larva (Col.: Carabidae) | 1 |
| Rove beetle adult (Col.: Staphylinidae) | 1 |
| *Agonum punctiforme* (Say) (Col.: Carabidae; ground beetle) | 1 |
| Total predation events | 162 |

Observations were made at 12:30, 16:30 and 2:00 over a single date.

the bead dishes when dishes were filled with soil/residue from the field, but the average number of these ancillary seeds was never more than 2.33 per dish per plot.

The total number of seeds consumed differed significantly among treatments and sample periods (treatments: $F_{2,9} = 7.72$, $P = 0.01$; sample week: $F_{2,18} = 70.13$, $P < 0.0001$, treatment × week: $F_{4,18} = 1.69$, $P = 0.19$). Mean weekly seed removal rates were 63.86 ± 10.21, 49.92 ± 7.03, 36.39 ± 7.31, in the low-, high- and intermediate-intensity treatments. Seed removal was significantly higher during the middle week (13 September) than the other two ($F_{2,33} = 56.66$, $P < 0.0001$). Rainfall occurred only during the second sample week (5.25 cm).

Granivores showed a preference for certain species of weed seeds. Significantly different numbers of seeds were consumed for each species (Fig. 3) ($F_{6,77} = 15.39$, $P < 0.001$). On average, more grass seeds of each species were removed than for broadleaf species ($F_{1,82} = 32.88$, $P < 0.0001$). There was also a slight trend for preference of lighter seeds over heavier seeds, although this relationship was not significant ($F_{1,5} = 4.78$, $P = 0.082$).

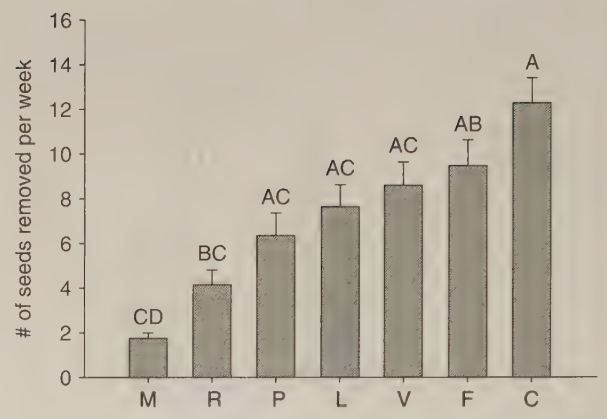


**Figure 3.** Mean ± SEM preference for weed seed species by granivorous arthropods. The average number of seeds (SEM) consumed per plot over 3 weeks ($n = 12$). Seed species were crabgrass (C), foxtail (F), velvetleaf (V), lambsquarter (L), redroot pigweed (P), giant ragweed (R) and ivyleaf morning glory (M). Bars with different letters are significantly different ($\alpha = 0.05$, Tukey HSD).

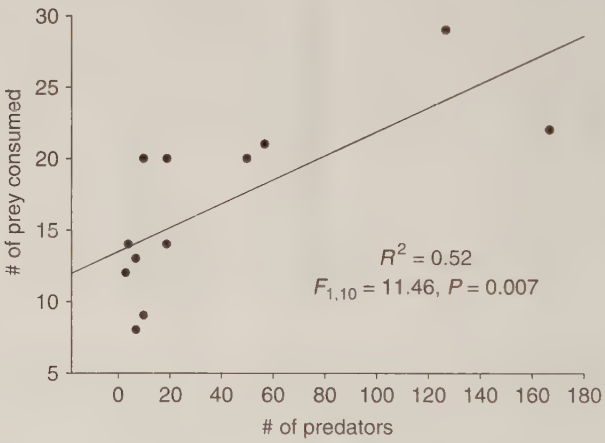


**Figure 4.** Predation rate on caterpillars (*G. melonella* larvae) versus insectivore abundance. Insectivore abundance (per $m^2$) was determined using quadrat samples. Predation on *G. mellonella* larvae was monitored for 10 h over three periods of a single date.

### *Sample methods and biological control indices*

Insectivory rates were significantly correlated with the quadrat sample estimates ($R^2 = 0.52$, $F_{1,10} = 11.46$, $P = 0.007$) (Fig. 4) but not with pitfall samples ($R^2 = 0.02$, $F_{1,10} = 0.21$, $P = 0.66$). The total number of seeds removed per plot was not well correlated with granivore numbers in the quadrat samples ($R^2 = 0.12$, $F_{1,10} = 1.33$, $P = 0.28$) or in the pitfall samples ($R^2 = 0.07$, $F_{1,10} = 0.71$, $P = 0.42$).

## Discussion

Farm management intensity has important implications for the activity and abundance of beneficial arthropods. Pitfall and quadrat samples revealed contradictory

information about the communities of biological control agents. Actual abundance of beneficial arthropods was a better indicator of biological control potential than activity estimates. In general, predators of insects and weeds were favored in the low-intensity transition system, and the beneficial arthropod communities behaved differently in the different management treatments.

Pitfall sampling revealed a shift in the activity of arthropod communities as the transition process proceeded. The number of predator species captured in pitfall traps increased from 2003 to 2004 (Table 1). But the activity of insectivores in the low-intensity treatment dropped considerably from 2003 to 2004, while activity remained consistent in the high and intermediate intensity treatments (Fig. 1). Actual densities of insectivores (as measured in the quadrat samples) in the low-intensity treatment far exceeded those found in the other treatments, and diversity was also much greater (Fig. 2).

Clearly, the quadrat and pitfall sampling methods captured different components of the biological control community. We hypothesize that the differences between these sample methods can be explained in part by the relative stability in the different treatments over time. Pitfall samples estimate the activity of a community and do not give a reliable measurement of actual densities or community constituency[18,25]. The activity of ground-dwelling arthropods can be impacted by a number of factors[18,26]. The capture rate by pitfall traps appears to be reduced in stable habitats because the movement of arthropods is impeded relative to that in open habitats characteristic of conventional agriculture[27,28]. In 2004, many more predators were found in quadrat samples in the low-intensity treatment relative to the other treatments, but the activity of these predators was not reflective of this trend in abundance (compare Figs. 1 and 2). The low-intensity treatment was planted with a diversity of forage crops in 2003 and had not been cultivated during the 2-year experiment. These factors led to a complex and stable habitat that supported a large number of niches for a higher diversity and abundance of predators to exploit but reduced the ability of these predators to move long distances quickly, hence the low pitfall capture rate in this treatment. In contrast, the similarity in pitfall captures within the high- and intermediate-intensity treatments may simply reflect the year-to-year constancy in the ability of arthropods to move in these treatments. The general increase in the number of species from 2003 to 2004 (Table 1) may be an acclimation of the biological control agents to the treatment regimen. For instance, smaller plots, increased plant diversity, and reduced levels of chemical inputs are factors known to positively affect the diversity of predator communities (reviewed by Kromp[2]). We observed all of these habitat characteristics in our experimental plots over the 2-year period.

In this study, predator abundance rather than activity estimates was a better indicator of our insectivory index (i.e. biological control of insects). Similar to our results, Brust et al.[15] found quadrat samples to be well correlated with predation rates in cornfields. Not surprisingly, not all of the predators observed in the density samples (Table 2) were major consumers of late-instar *G. melonella* larvae (Table 4). Spiders were the most abundant predators, but many of these were smaller species (such as Lyniphiidae) that are not active or large enough to kill and eat large, mobile prey[29]. In spite of the fact that the entire predator community does not attack large prey, the number of *G. melonella* larvae consumed over the day was strongly correlated with the abundance of insectivores present in the plot (Fig. 4).

The management treatments led to varying insectivory rates and daily predation patterns, suggesting that natural enemy communities behaved differently in the assorted cropping systems. The highest levels of insectivory occurred in the low-intensity system, and these levels were consistent over the entire day (Table 3). In contrast, predation occurred predominantly at night in the high-intensity treatment (Table 3), even though predator densities did not differ substantially over the day in this treatment (Fig. 2). This suggests that either different biological control agents reside in more intensively managed fields, or that key predators of lepidopteran larvae behave differently in these systems. In cornfields, Brust et al.[15] found daily insectivory patterns similar to those observed in our highly managed system, suggesting that there may be a characteristic predator community associated with ephemeral cropping systems. Certainly, a strong precedence of habitat or crop selection by specific species of insectivores has been well established[10,14,16,30]. A next step in our research program will be to determine whether the cropping system selected during the transition process and the accompanying biological control agents have long-term effects on biological control after the transition process has ended.

Granivory by arthropods was influenced by farm management intensity, and granivores showed preferences for certain weed species. The low-intensity treatment had higher seed removal rates than the others, which may be related to the reasons discussed for the higher levels of insect predation in this treatment. Seed preference appeared to be greatest for grass species (Fig. 3) and was independent of seed size. For instance, more *Ag. abutilon* seeds were removed than *C. album* or *Ama. retroflexus* seeds, despite the preferred seeds being ten times the weight of the less preferred species. This suggests that plant seeds may be differentially prone to granivory based on their morphological (i.e. seed coat thickness) or physiological (i.e. internal chemistry) characteristics or 'defenses'[31].

Granivory peaked during the second week of the observation period, the only week to experience rainfall. This may be a demonstration in the field of granivores preferring seeds that had imbibed moisture compared to dry seeds. We hypothesize that soil moisture resulting from rainfall is important in regulating granivory rates. No rain fell during the first and third weeks of the

observation period, but more than 5 cm fell during the second week; seed consumption was 4-fold higher during this period compared to the adjacent weeks. In the laboratory, we observed that *Harpalus pensylvanicus* and *Anisodactylus sanctaecrucis*, two abundant granivorous species in our plots (Table 1), preferred moistened seeds over dry ones (J.G. Lundgren, unpublished data). This may be in part due to the relative ease with which the seed coat of wet seeds can be penetrated. Preference for imbibed seeds has been observed in other granivorous insects as well[23,32]. Rainfall should be a consideration of future field studies involving granivory rates.

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# Linkages between organic agriculture and agro-ecotourism

Nae-Wen Kuo[1,2]*, Yin-Jen Chen[1], and Chiou-Lien Huang[1]

[1]Graduate Institute of Tourism and Health Science, National Taipei College of Nursing, Taiwan.
[2]Research Center of Environmental System, National Taiwan University, Taiwan.
*Corresponding author: ibis@ntcn.edu.tw or nivenkuo@ntu.edu.tw

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## Abstract

Organic agriculture is regarded as one important approach to agriculture and food production that is environmentally sustainable and can generate several positive impacts to rural society. However, organic agriculture development is still limited in Taiwan and the major reason is lack of economic incentives to farmers. Hence, one approach to link organic agriculture with agro-ecotourism is proposed in this study to maximize the economic benefit of organic agriculture.

Chrshang Township in Taiwan was selected as an example to develop such eco-organic tourism based on organic agriculture. First, five appropriate activities were designed according to the fundamental principles for guiding the development of eco-organic tourism. In addition, the maximum willingness to pay (WTP) method was employed to estimate potential revenues from eco-organic tourism and then the economic value could be compared with that of other economic activities. Under a conservative scenario, the total annual revenue from eco-organic tourism is about NT$421,293,559, which is about 20 times that of the rice production in the study area.

In addition to the direct economic revenues, the following additional benefits can also be found: (1) the linkage can create additional value of organic agriculture; (2) organic agriculture can contribute to service economy and experience economy; (3) people can increase their confidence in organic products through better understanding; (4) a one-step relationship between organic producer and consumer can be established; and (5) local food supply will be connected with demands in the tourism industry. In summary, under a symbiotic relationship, organic agriculture is not only commodities and goods production, it can become one important service economy and even create experience economy within the tourism industry.

**Key words:** organic agriculture, agro-ecotourism, eco-organic tourism

## Introduction

Organic agriculture is regarded as one important approach to sustainable agriculture and has several positive impacts to rural environment in comparison with conventional farming. However, organic agriculture development is still limited in Taiwan and the major reason is lack of economic incentives to farmers. Hence, linkages between organic agriculture and other activities in rural areas should be investigated to increase the additional benefits of organic agriculture other than organic products themselves. Agritourism, an important element of the diverse activities in rural areas of Taiwan, may be a suitable activity to be connected with organic agriculture because, if the relationship between tourism and food production is symbiotic, both sectors can mutually benefit from each other[1]. Socher and Tschurtschenthaler[2] categorize agriculture as having two separate but linked supply values for the tourism industry. The first is direct supply, which involves the sale of agricultural products to the industry. The second is indirect supply, which involves preservation and cultivation of the landscape which acts as a backdrop or tourism resource. In addition, Adam[3] has concluded that agritourism and entertainment farming, highly consumer-focused types of agriculture, may offer additional options for diversifications, adding stability to farm incomes.

However, which kind of agritourism activity is optimal to be linked with organic agriculture? Four types of relationships between organic agriculture and agritourism will be discussed first in this study. Eco-organic tourism, an agro-ecotourism activity advocated by the Food and Agriculture Organization (FAO) of the United Nations[4], may be the first candidate because it is planned and managed according to the principles of ecotourism and may result in a relatively low impact compared to others. However, is such a linkage between organic agriculture and

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agro-ecotourism feasible in Taiwan? Can eco-organic tourism based on organic agriculture attract tourists and then generate economic benefits? Does it have other additional benefits for different sectors?

Chrshang Township in Taiwan is selected as an example to study the feasibility of various innovation activities based on organic agriculture and eco-organic tourism because its proportion of organically managed areas exceeds that in the rest of Taiwan. In addition, about 514,000 tourists visit Chrshang Township for rural recreation annually. First, the maximum willingness to pay (WTP), one approach of the contingent valuation method, will be employed to estimate potential revenues from eco-organic tourism in Chrshang Township and then the results can be compared with other economic activities. Furthermore, except for direct economic revenues from eco-organic tourism, the additional benefits to each of both sectors will also be investigated in this study when the relationship between food production (organic agriculture) and tourism (eco-organic tourism) is symbiotic.

### *Organic agriculture and agritourism in Taiwan*

Organic agriculture is one of the most prominent forms of sustainable production. The literature states that organic agriculture has several positive impacts and organic agriculture is regarded to play an important role in sustainable development in rural areas[4–10]. In Taiwan, farmers started to adopt organic farming practices in the 1970s, but the growth rate is still slow. Up to now, only 0.3% (10.92 $km^2$) of total agricultural area is managed according to organic farming guidelines[11]. Consequently, organic agriculture development is limited in Taiwan and the major reason is lack of economic incentives to farmers[12,13].

The symbiotic relationship between agriculture and tourism that can be found in agritourism (agrotourism) is a key element of environmentally and socially responsible tourism in rural areas[4]. With the decline in agriculture (for example, only 1.9% of GDP in 2001), the Council of Agriculture (COA) in Taiwan has tried to develop recreational activities in rural areas since 1988. All (369) country towns have created recreational activities related with agriculture, and 173 holiday farms have been established for tourism with the increasing demand of agritourism[14]. For most rural communities in Taiwan, agritourism is one of the important elements in their diversified economy. For some others, such as Ching-Chin, Chi-Chi and Shwei-Li in Nantou County, agritourism has become the primary economic endeavor which dominates community life and upon which the local area is dependent. However, the linkage between tourism and agricultural production is still weak and sometimes the relationship is in a conflict over competition for land, water resources, labor and capital in Taiwan's rural areas[15]. Moreover, various negative impacts to the rural environment have resulted from agritourism (especially mass agritourism activities)[16].

## Region of Study

Chrshang Township in Taitung County (located in the east of Taiwan) is selected to develop eco-organic tourism based on organic agriculture in this study, because people in the township are more interested in organic agriculture than others. It covers an area of 82.69 $km^2$ with a population of 10,715[17]. The agricultural area amounts to 40.12 $km^2$, 11% of which is managed according to organic farming guidelines[17]. This proportion of organically managed area exceeds that of the rest of Taiwan. Some local farmers have tried to adopt organic farming since 1994, and they have promoted this low-impact agriculture to other farmers with the aid of the active local non-government organization, Wan-An Village Development Association (established in 1993). At present, their organic products are all certified by the MOA (Mokich Okada International Association, established in Japan in 1935), which is the major organic products labeling system in Taiwan.

In addition, about 514,000 tourists visit Chrshang Township annually not only because of the beautiful landscape and wildlife resources, but also because of the attraction of 'Chrshang Rice' and 'Chrshang Boxed Meal'. Due to the clean water, suitable soil and warm climate, rice cultivation in Chrshang is successful and famous among the Taiwanese, and its products ('Chrshang Rice' and 'Chrshang Boxed Meal') are well known.

## Methods

The maximum WTP will be employed in this study in order to estimate potential revenues from eco-organic tourism. Methods available to assess the tourism value may be categorized as market based and non-market techniques. Non-market methods include indirect (travel cost) and direct (contingent valuation) measures[18]. The maximum WTP, one approach of the contingent valuation method (CVM), employs hypothetical questions to elicit respondents' maximum WTP for a specified situation[18,19]. Moreover, 'the payment card'[20,21] format, such as the example question in Table 1 is used in this study. The CV question used in this survey provides a detailed description of the five hypothetical scenarios, which are based on the appropriate activities designed for Chrshang Township.

These five appropriate activities were designed according to the fundamental principles of eco-organic tourism, and the opinions of the local community. The fundamental principles for guiding the development of eco-organic tourism based on organic agriculture were established after

**Table 1.** Question eliciting information on tourists' WTP use fee.

| |
|---|
| How much would you be willing to pay as per person use fee to participate in the organic farming activity, in addition to the other costs of the trip?<br>___NT$0, ___NT$150, ___NT$300, ___NT$450,<br>___NT$600, ___other (please specify) NT$___. |

**Table 2.** The fundamental principles of eco-organic tourism.

| | |
|---|---|
| Objectives | Eco-organic tourism development is based on organic agriculture in combination with ecotourism to provide acceptable recreation opportunity without destroying the natural rural environment |
| Principles | 1. Agricultural activities are based on organic farming. |
| | 2. Tourism and recreation activities are managed according to the principles of ecotourism. |
| | 3. Emphasize environmental protection and natural conservation. |
| | 4. Respect traditional culture of local village. |
| | 5. Protect diversity of ecosystems, agricultural activities and traditional culture. |
| | 6. Local benefit. |
| | 7. Provide healthier, safer food, and recreation services. |
| | 8. Promote organic agricultural activities as a most effective means for landscape conservation. |
| | 9. Offer additional economic resources for organic products. |
| | 10. Provide feasible economic resources to environmental protection. |

the *ad hoc* committee meeting held by the local government of Chrshang Township in November 2003 (Table 2). In addition, three rounds of workshop meetings were held to collect the opinions of local people by the local government of Chrshang Township, with the aid of the Wan-An Village Development Association during January and February 2004. Diverse opinions were collected but some activities (such as horse riding) are unsuitable because their relationship with organic agriculture is weak.

A pilot survey of the maximum WTP was carried out among agritourism tourists at Chrshang Township during July and August 2004. The sampling population for the study was established as 'tourists who visit Chrshang Township either directly or by the way'. Non-probability, convenience sampling was selected as the most appropriate way to access this population given the limited time and resources available for the survey implementation.

## Results

First, 992 effective questionnaires were gathered in the maximum WTP survey, and the main tourist characteristics are listed in Table 3. The survey results indicate that the study destination attracts highly educated tourists (college educated: 54.3%) and their average monthly income is about NT$20,000–40,000 (32.3%). The average length of the tourists' stay at Chrshang is 1.60 days and this may indicate that a demand exists for accommodation; hence, the local people may try to develop bed and breakfast (B&B) or inns. In addition, in this pilot survey 70% of total tourists attended eco-organic tourism activities.

**Table 3.** Agritourism tourists sample characteristics.

| Characteristics | Tourists in Chrshang ($N = 992$) |
|---|---|
| Male | 56.3% |
| Average age | 36.8 |
| College educated | 54.3% |
| Average length of stay at Chrshang (days) | 1.60 |
| Average monthly income (NT$) | 20,000–40,000 (32.3%) |
| Recreation expenditures (NT$/month) | 2500–5000 (42.6%) |

Finally, the maximum WTP of each hypothetical activity can be found in Table 4. The 'participate in organic farming' activity received the highest WTP value, while the 'cycle routes within agricultural lands' activity had the lowest value. This may because the 'participate in organic farming' activity is not easily found around Taiwan but bike riding activities are common and can be experienced in many destinations of Taiwan. The 'organic meals and food provided' activity also received higher values and this result may indicate that tourists would be willing to pay a higher price to have more wholesome and healthy food during the trip.

## Discussion

### *Eco-organic tourism may be the optimal activity to link organic agriculture with tourism*

Agriculture and tourism have the potential to work together in a symbiotic relationship or just coexist in the rural areas. Four types of possible relationships between agriculture and tourism are listed in Table 5. In general, type A can be regarded as mass agritourism, and is the most popular type in rural areas around the world. However, because the intrinsic characteristic of type A is tourism, it often ignores the agriculture sector and may generate negative impacts to the rural environment. Several studies, such as Bryden (1973)[22] and Weaver (1988)[23], stress competition for the resources of land and labor between agricultural production and tourism.

In order to conserve biodiversity, ecotourism is advocated to link with agriculture in rural areas. For example, the Convention on Biological Diversity (CBD) of the United Nations, often emphasized the linkages between ecotourism and agriculture: 'ecotourism provides full and effective participation and viable income-generating opportunities for indigenous and local communities' (Decision V/25, 4a). Types C and D are the potential activities based on ecotourism connected with agriculture and they are often named agro-ecotourism. While ecotourism is nature-based

**Table 4.** WTP of hypothetical activities.

| Activities | Average WTP (NT$) | Standard deviation (NT$) |
|---|---|---|
| Participate in organic farming | 415.02 | 73.47 |
| Organic meals and food provided | 320.40 | 76.04 |
| Environment education and interpretation | 203.04 | 70.68 |
| Cycle riding within agricultural lands | 107.02 | 29.32 |
| Participate in special events with local community | 126.21 | 58.02 |

and agritourism is farm-based, agro-ecotourism is a combination of both. In general, the rural landscape, usually a combination of wild and agri-ecosystems, is the most important resource for ecotourism development except for national parks and protected areas. There are some successful examples in different countries to explain that agro-ecotourism can provide a strong economic incentive to small farmers to commit to biodiversity friendly agriculture management[4].

Eco-organic tourism (type D), may be the optimal activity to link organic agriculture with tourism because both organic agriculture and ecotourism are aimed at reducing the environmental impacts and contribute to natural conservation. People establish organic agriculture with a strong emotional commitment to nature, the environment, animal welfare and health, and similar land ethics can also be found in ecotourism. Hence, the negative impacts from eco-organic tourism to the rural environment may become relatively lower than other agritourism activities. If organic agriculture is connected with mass tourism (type B), the resource problems may pollute the rural environment and affect organic agriculture production. Furthermore, eco-organic tourism may attract more ecotourists and environmentalists than other agritourism activities because these visitors have a more ecocentric attitude towards nature and prefer businesses that are environmentally friendly. In addition, visitors are increasingly sensitive to quality, both in ecological and gastronomic terms, and this trend can favor organic farmers because they can easily meet these new tourists' demands with the connection between catering service with organic production.

A 1999 survey in Italy reported that eco-organic holiday farms performed the following activities: 35% arrange visits to nearby protected areas; 30% plan naturalistic didactical activities; 24% set up didactical and demonstrative laboratories on organic agriculture and the environment; and 11% offer visitors instruments and equipment for the observation of fauna and flora[24]. Several studies in the European Union have demonstrated the ability of organic agriculture to create attractive landscapes and activities for tourism[4]. Eco-organic farm practices and activities which benefit the environment while rewarding farmers include: accommodation in buildings renovated according to ecological architecture, on-farm consumption or selling of organic foods and beverages, educational programmes and training (e.g. organic gardening, compost making, wild herb collection and drying, traditional food and beverage processing), and sensitizing guests on the rational use of natural resources.

**Table 5.** Four types of relationships between agriculture and tourism.

| | Conventional agriculture | Organic agriculture |
|---|---|---|
| Mass tourism | A | B |
| Ecotourism | C | D |

### *The potential revenues from eco-organic tourism in Chrshang Township*

According to the findings of this study, tourists prefer to participate in organic farming among the five hypothetical activities when they visit Chrshang Township and are willing to pay NT$415.02. This may be because many tourists who come from urban areas lack the opportunity to participate in organic farming activities; hence, they prefer to attend organic agriculture activities such as insect scratching, undergoing a more rural tourism experience. 'Organic meals and food provided' is the second activity that can attract tourists and the average WTP is NT$320.40. It indicates that meals made from local organic products are welcome by tourists although the price of organic meals is higher than that of common meals. The meals that are provided to tourists on their eco-organic trip may be named 'organic meals' and 'green treasures', emphasizing that all materials are organic products and cultivated by local farmers. In addition, in order to emphasize 'good for health,' a dietician can design these organic meals, and the issue about nutrition balance can also be taken into account.

In addition, appreciation of the environment education and interpretation activity by tourists is also high since the content of environmental education and interpretation in eco-organic tourism is abundant and diverse. The content is not restricted to the natural environment, which is often emphasized by ecotourism in the protected areas; community history, traditional lifestyle, traditional events and other cultural materials can also be included. Furthermore, the concepts of sustainable agriculture, and the agricultural procedures of organic farming, may become the main contents of environment education and they can become other interesting issues for interpretation.

**Table 6.** Estimates of total potential annual revenues from various activities.

| Activities | Conservative scenario (NT$) | Non-conservative scenario (NT$) |
|---|---|---|
| Participate in organic farming | 149,224,840 | 213,178,343 |
| Organic meals and food provided | 115,203,216 | 164,576,023 |
| Environment education and interpretation | 73,005,184 | 104,293,120 |
| Cycle riding within agricultural lands | 38,480,175 | 54,971,679 |
| Participate in special events with local community | 45,380,143 | 64,828,776 |
| Sum | 421,293,559 | 601,847,942 |

Cycle riding within agricultural lands is another innovation activity and seems feasible in Chrshang Township since cycle tourism is a popular activity in Taiwan and farmers in Chrshang Township agree the cycle routes that are established around their private lands. However, the WTP of 'cycle riding within agricultural lands' is about NT$107.02 per tourist, the lowest one among the hypothetical activities. This may be because tourists lack expectations about cycle riding since it is a common activity around Taiwan. Regardless, cycle riding may generate additional benefits to the local community because bicycle rent may be another economic income for local people. Hence, the local government has planned to establish some cycle routes within agricultural lands and develop the cycle networks to connect different viewpoints within the rural areas. The WTP of 'participate in special events with local community' is about NT$126.21 per tourist, and it also shows a lower value than that expected. In fact, this activity cannot only be assessed in terms of direct economic benefit. The self-confidence of local people, traditional culture preservation, and different cultural experiences shared with tourists can also be contributed to such an activity.

According to the accounted data of the local government[17], the annual number of tourists is 513,658. This number of total visitors is used as a non-conservative scenario, while a conservative scenario assumes that 70% of total tourists will attend eco-organic tourism activities, according to the findings of this study. If the average WTP elicited in this survey at Chrshang is instituted as the entrance fee or activity charge (assuming that the WTP distribution of our sample represents the WTP distribution of the agritourism population visiting Chrshang), the potential annual revenues can be estimated (Table 6). The total annual revenue under a conservative scenario is about NT$421,293,559, which assumes each activity receives 70% of total tourists.

Although agritourism has been developed in Chrshang, the economic benefit cannot be calculated because the essential data are not available. In addition, the current agritourism activities are mass tourism type and external tour operators often organize them as package products. Most of the economic benefit is directly to the tour company, and the rest of the revenues cannot contribute significantly to local economy. In contrast, rice production is the major contributor to the local economy of Chrshang now and it is clear that the revenue of rice production affects the income levels of farmers and local people. Hence, the economic benefit of rice production is calculated as a control for comparison in this study.

The annual revenue of rice production is calculated under three different situations: (1) assuming rice production in Chrshang is all from conventional farming; (2) assuming rice production in Chrshang is all from organic farming; and (3) real rice production in Chrshang. The annual revenues of rice production would be NT$19,077,000–28,615,500 (Table 7).

In comparison, the annual revenue from eco-organic tourism is the most potential economic activity to the local community and will be 20 times that of the rice production. Moreover, if organic agriculture is connected ideally with eco-organic tourism in Chrshang; i.e. rice production in Chrshang is all from organic farming, together with the eco-organic tourism activities proposed here, the sum of annual revenue could reach NT$449,909,059.

### *Additional benefits from eco-organic tourism*

In addition to the potential revenue from eco-organic tourism mentioned above, such linkages between organic agriculture and agro-ecotourism may form a symbiotic relationship and both sectors can mutually benefit from each other. Under linkages between organic agriculture and agro-ecotourism, various benefits may be generated to

**Table 7.** Comparison of annual revenues from eco-organic tourism with other activities.

| Economic activities | Annual revenues (NT$) |
|---|---|
| Rice production with 100% conventional farming | 19,077,000[1] |
| Rice production with 100% organic farming | 28,615,500[2] |
| Real rice production in Chrshang (organic farming:11%; conventional farming: 89%) | 20,126,235[3] |
| Eco-organic tourism in this study | 421,293,559 |

[1] 12,718 (tons $yr^{-1}$) × 1500 (NT$ $ton^{-1}$) = 19,077,000 (NT$).
[2] 12,718 (tons $yr^{-1}$) × 75% × 3000 (NT$ $ton^{-1}$) = 28,615,500 (NT$).
[3] 19,077,000 × 89% + 28,615,500 × 11% = 20,126,235 (NT$).

**Table 8.** Additional benefits from eco-organic tourism.

| Benefits to organic agriculture | Benefits to agritourism |
|---|---|
| 1. It can provide an opportunity for tourists to recognize what organic agriculture is; | 1. Better rural environmental quality can attract more tourists; |
| 2. People can understand the high degree of labor power input in organic agriculture; | 2. Organic agriculture itself can provide attractive recreation resources to tourism; |
| 3. People can experience the hard work in the field through participating in organic farming; | 3. Organic agriculture is good material for environmental education and interpretation; |
| 4. Customers can have more confidence in organic products; | 4. Organic agriculture can provide food resources to the catering system; |
| 5. Customers can purchase organic products from producers directly; | 5. Food and drink are wholesome, absent of chemicals, environmentally friendly, and better tasting; |
| 6. It can generate additional income to organic farmers; | 6. Special gifts and souvenirs for tourists can be produced locally; |
| 7. It can establish various market approaches of organic products; | 7. Organic agriculture can bring the images of 'health' (market distinction); |
| 8. It may help to promote organic agriculture. | 8. 'Green' image of both eco-organic tourism and organic agriculture (market distinction). |

several sectors such as agriculture, food, tourism and local community. According to the experts' opinions in this study, the direct and indirect benefits to organic agriculture from such linkages are summarized in Table 8.

In general, doubt about organic products reduces the willingness of consumers to buy organic products from supermarkets[25,26]. Such linkages can provide consumers the opportunity to understand the specific organic method of production, and then customers may increase their confidence in organic products. In addition, the relationship between producer and consumer can become a one-step relationship instead of the complex network relationship and reduce the difficulties among various sectors in a network relationship under such linkages. First, tourists can buy organic products directly from farmers during their trip, generating additional income to organic farmers. According to the findings of this study, 90% of tourists want to buy organic products directly during their trip. Secondly, tourists who have experienced eco-organic tourism may start to buy organic products in their daily life. For example, in this study 78% of tourists after their trip continue to buy organic products from Chrshang by telephone order.

Moreover, organic agriculture, together with eco-organic tourism may also contribute several positive efforts to agritourism or rural tourism development, listed in Table 8. For example, expanding the backward economic linkages by increasing the amount of local food used in the tourism industry since food represents approximately one-third of all tourists' expenditures[27].

## Conclusions

In general, organic agriculture can generate several positive impacts to the ecological, social and economic environment and is regarded as having a dominant influence in the rural environment. However, organic agriculture development is limited in Taiwan and the major reason is that the relationship between the organic producer and the consumer is a complex network and many difficulties decrease the willingness of the producer to farm organically. Hence, one approach to link organic agriculture with agro-ecotourism is proposed in this study, in order to increase the additional benefits of organic agriculture except for organic products themselves.

Eco-organic tourism, one type of agro-ecotourism, may be the optimal choice to be connected with organic agriculture because both of them are concerned about nature conservation, environmental protection and sustainable development. Other agritourism activities will act like mass tourism and may result in negative impacts to the rural environment and even affect the organic production. In comparison, eco-organic tourism based on the principles of ecotourism will limit the development scale of tourism and the number of tourists would be more environmentally friendly.

According to the findings of this study, the linkage between organic agriculture and agro-ecotourism is feasible and eco-organic tourism activities based on organic agriculture can attract tourists. Under a conservative scenario, the total annual revenue from eco-organic tourism is about NT$421,293,559, which is about 20 times that of the rice production in the study area. Moreover, the sum of the annual revenue will reach NT$449,909,059, which is the economic value of organic rice production added to the economic value of tourism.

In addition to the direct economic value of eco-organic tourism, there are other additional benefits by which both sectors can mutually benefit from each other. In brief, the following main additional benefits could be found

under the linkage between organic agriculture and agro-ecotourism: (1) it can create an additional value of organic agriculture (in particular, the recreational value); (2) organic agriculture is not only commodities and goods production, it can become one important service economy and even create experience economy[28] within the tourism industry; (3) people can understand what organic agriculture is and increase their confidence and reliability in organic products; (4) it can establish a one-step relationship between the organic producer and consumer and reduce the difficulties among various sectors in the network relationship; and (5) local food supply can be connected with demands in the tourism industry (in particular, organic products).

In summary, organic agriculture can become an attractive tourism resource and attract tourists to visit rural areas, and eco-organic tourism can generate more economic benefits than organic production itself. Consequently, the value of organic agriculture is not only within the commodities and goods economy. Organic agriculture has potential to become an important sector in service economy and experience economy when it is connected with the tourism industry.

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# Soil microbiota effects on rye growth: implications for integration of a rye cover crop into temperate cropping systems

Jason L. De Bruin[1,*], Nicholas R. Jordan[2], Paul M. Porter[2], and Sheri C. Huerd[2]

[1]Department of Agronomy, Iowa State University, 2104 Agronomy Hall, Ames, IA 50011, USA.
[2]Department of Agronomy and Plant Genetics, University of Minnesota, 411 Borlaug Hall, 1991 Buford Circle, St Paul, MN 55108, USA.
*Corresponding author: jsndbrn@iastate.edu.

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## Abstract

Integration of rye (*Secale cereale* L.) cover crops into the corn (*Zea mays* L.) soybean [(*Glycine max* (L.) Merr.] rotation of the upper Midwest USA can provide many agronomic and agroecological benefits. Integration is made difficult by short growing seasons, but may be facilitated by management of key agroecological interactions such as those between rye and soil microbiota. Rye growth was measured and colonization by arbuscular-mycorrhizal fungi (AMF) was determined in greenhouse experiments using soils from seven different management systems from a long-term cropping-systems experiment in southwest Minnesota. Microbial effects on rye growth were not evident before vernalization, but at final harvest (4 weeks after vernalization) soil microbial populations reduced rye shoot and root growth, relative to a pasteurized control inoculum. At final harvest, shoot biomass in 2-year rotations was 17% greater than 4-year rotations, indicating that microbial populations selected for by 4-year rotations may be more deleterious or pathogenic than those selected for by 2-year rotations. Growth of three rye cultivars was examined in all inocula; cultivars differed in their mean response to soil microbiota and their ability to host AMF. These findings suggest that management factors affect interactions between rye and soil microbiota resulting in altered rye growth.

**Key words:** cover crop, crop rotation, mycorrhizal fungi, organic, rye, *Secale cereale*, soil microbiota

## Introduction

Cover crops provide a well-documented range of benefits including contributions to soil quality and fertility, nutrient management, erosion control, and pest management[1]. The importance of cover crops may increase as societal expectations of agriculture evolve. For example, cover crops are likely to be an important strategy for farmers engaging in carbon trading or modifying management to meet total minimum daily load (TMDL) requirements. In the upper Midwest, winter cover crops must be established during a short temporal window making this operation both difficult and risky[1–3]. Optimal agronomic functioning of winter cover crops depends on rapid early biomass accumulation the following spring season. Adoption of cover-cropping practices would likely increase if reliability of establishment and biomass production were increased. Cover-crop breeding[4] and development of technology used in cover-crop management such as planters and tillage implements may lead to such increases.

Cover crops interact with many organisms in agroecosystems, and serve as critical links in a number of agroecological processes and cycles[5]. Through these interactions, cover crops influence and are influenced by other elements of biodiversity. Interactions between plants and soil microorganisms are increasingly recognized as important factors in agroecosystems[6–8] and management of these interactions may offer additional options for improving the integration of cover crops into cropping systems.

Analysis of cover crop interactions with soil microbiota has largely emphasized effects of cover crops on microbiota. Cover crops increase total microbial biomass[9–11] and increase populations of beneficial microbiota such as arbuscular-mycorrhizal fungi (AMF). Certain cover crops can provide a live host for AMF colonization during long winter-fallow periods, thus improving AMF survival and

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subsequent colonization of crops[12–15] and crop P nutrition[16,17]. Cover crops have also been shown to both increase[18] and to decrease[19] the abundance of soil-borne pathogens. These studies suggest that cover crops may be important instruments for management of soil microbiota.

Very little is known about effects of beneficial or pathogenic soil microbiota on cover crops. It is possible that interactions with soil microbiota positively affect cover-crop establishment and growth since beneficial microbiota, such as AMF and growth-promoting rhizobacteria[7,20,21], can have strong effects on plant growth, nutrition and stress resistance. Conversely, pathogenic microbiota are increasingly understood as important limiting factors even when obvious disease symptoms are not present[22,23]. It is possible that cover-crop establishment and early biomass accumulation could be improved in cropping systems managed to increase populations of beneficial microbiota, and/or to reduce abundance of pathogens that interfere with cover-crop establishment and growth. In the only relevant study known to us, large differences occurred among cropping systems on colonization of winter rye by AMF[24], supporting the hypothesis that management factors may influence cover-crop interactions with soil microbiota. Unfortunately, there appear to be no detailed experimental investigations of these possibilities in published literature.

In temperate areas rye is frequently chosen by farmers using winter cover crops, because of a range of desirable attributes such as winter hardiness, early spring growth and high biomass production[25]. However, in the upper Midwest, rye establishment following corn or soybean is complicated by a relatively late planting date. It is therefore important to identify management factors that could affect rye establishment and growth the following spring season. Accordingly, we examined how rye responded to soil microbiota from the Variable Input Crop Management Systems (VICMS) experiment located at the University of Minnesota Southwest Research and Outreach Center near Lamberton MN. The VICMS experiment was established in 1989; its treatments consist of four different management levels (minimum, low, conventional and organic input levels), each applied to one 2-year and one 4-year crop rotation. The experiment was established on a field that had a history of very few inputs and very low soil P levels. A complete description of the rotations, management treatments and associated crop yields was reported by Porter et al.[26]. These varying management systems are likely to cause differentiation among communities of AMF[27,28] and other soil microbiota[29,30] and certain soil-microbiological differences among VICMS treatments have been documented. Early in the VICMS study, AMF spore populations and colonization rates were higher in low-input than in conventional treatments[31]. Recently, others have documented that total microbial biomass was higher in organic and reduced-input treatments than in conventional ones[32]. In addition to assessing the net effect of soil microbiota from various management systems on early growth of rye, we examined two other related issues. First, we determined AMF colonization in rye grown in soils from these management systems, to assess whether positive or negative effects of soil microbiota on rye growth were associated with AMF colonization. Second, we conducted our experiments with three rye cultivars. It is plausible that effects of soil microbiota on cover-crop performance might differ among cover-crop cultivars since such effects generally occur with field crops[33]. Little effort has been made to improve germplasm for cover-crop performance in most cover-crop species. Therefore, assessment of genetic differences in relations with soil microbiota is worthwhile, since breeding to improve these relations might be a useful part of a multifaceted approach in improving the integration of cover crops into cropping systems.

## Materials and Methods

Two greenhouse studies (Study I and Study II) were conducted to investigate the growth response of rye to soil microbiota and association with AMF in soils with varying management histories. In each study, the experimental design was a 3 by 8 factorial combination of three rye cultivars and eight soil inoculums with four rye harvest dates each with five replicates. Harvest 1 was approximately 14 days after planting; harvest 2, 28 days after planting; harvest 3, 14 days after a vernalization period; and harvest 4, 28 days after vernalization period. Thus, the first two harvests corresponded to post-establishment growth before winter, and the latter two corresponded to spring growth. The entire experiment was conducted twice; with Study I initiated in fall 2001 and Study II initiated in fall 2002.

The seven inoculum soils from the VICMS experiment were collected from 0 to 20 cm soil depth in the fall of 2001 and 2002. These soils are a complex of the Normania, Revere, Webster and Ves clay loams. Six of the seven inoculum soils were collected following corn production from either a 2-year or 4-year rotation, with a minimum (Min), conventional (Con) or organic (Org) management system. The seventh inoculum soil was obtained from the prairie treatment (Prairie), which was sown with a native prairie species mixture in 1989.

The 'base soil' used in both Studies I and II consisted of a 50 : 50 (by volume) mixture[34,35] of sand and a Typic Hapludoll (well-drained silt loam) soil from the Research and Outreach Center near Rosemount MN. This soil : sand mixture was steam pasteurized (twice for 60 min at 77°C) to eliminate soil biota while minimizing soil chemistry changes[36]. The base soil mixture was inoculated with 'inoculum' soil from each of the seven management systems (550 : 80, by volume; 15% inoculum) and was also used to provide a control treatment free of soil-microbiota. Plastic pots 6.4 cm in diameter and 25 cm in length were filled to 22 cm depth with the soil mix. Five rye seeds were placed in each pot, and covered with approximately 2.5 cm of soil mix. Seedlings were thinned to three per pot approximately six days after planting.

In Study I, plant shoots were clipped approximately 1 cm above the soil level at each harvest and allowed to re-grow. Whole plants (roots and shoots) were sampled 1 week after the fourth harvest, dried (55°C for 72 h) and weighed. In Study II whole plants (roots and shoots) were collected at each harvest, dried and weighed. Following the first two sample dates plants were vernalized at 4°C with a cycle of 16 h light and 8 h dark. After vernalization, plants in Study I were fertilized with approximately 12 ml pot$^{-1}$ of 15-0-0 fertilizer. No fertilizer was added in Study II, due to lack of visual nutrient deficiencies. Nutrient levels in experimental soil mixes were assessed in soil samples collected for each soil mixture from Study II after the first and fourth harvests; soil analyses were conducted by the University of Minnesota soils testing laboratory.

Harvested roots (from final harvest only for Study I; from all harvests for Study II) were analyzed for colonization by AMF. A sub-sample of plant roots was dyed using Aniline Blue[37] and colonization ratios were determined by counting the presence or absence of AMF structures (hyphae, arbuscules and vesicles) using a light microscope at 200× from 100 views per sample. Percent colonization was calculated based on presence or absence of AMF structures in each view.

Data were analyzed using SAS (SAS Institute, Cary, NC). Analysis was done separately for each study due to heterogeneity of variance. Colonization percent was transformed using arcsine transformation (arcsine $\sqrt{y}$) to normalize data for analysis[38]. There were no significant interactions between soil type and rye cultivar. Single degree of freedom contrasts were used to determine estimated differences between management systems, rye cultivars and combinations of both factors. Contrasts consisted of the following comparisons: agricultural systems (without the prairie) versus control, 2-year versus 4-year rotations for each management system and conventional versus minimum versus organic systems averaged across rotation length.

## Results

### *Shoot and root biomass*

In both studies, soil inocula from the various management-system treatments differed in their effects on shoot biomass in seven of the eight harvests in the two studies (Table 1). Shoot biomass production before vernalization (i.e., first and second harvests), was generally greater in inocula from organic systems than in inocula from conventional and minimum-input systems (Table 1). Inocula from 2-year rotations produced greater pre-vernalization shoot biomass than 4-year rotations. These effects on early seedling growth (14 and 28 days after planting) are best explained by the high nutrient levels present in inocula from organic rotations. Soil mixes (i.e., inocula plus base soil) from 2- and 4-year organic systems had P at 22 and 15 mg kg$^{-1}$, respectively, compared to approximately 8 mg kg$^{-1}$ for the other soils (Table 2) confirming field observations of high P levels in these same soils[26,32]. Field sampling also revealed a similar pattern of N levels among management systems[32] (N levels were not determined in inoculated soils used in Studies I and II). Specifically, N values were greatest in the organic management systems at approximately 16.0 and 8.0 ppm for 2- and 4-year rotations, respectively. Nitrogen values from the minimum and conventional management systems were approximately 2.5 and 8.0 ppm for both 2- and 4-year rotations, respectively[26,32]. The relatively high nutrient levels observed in organic management treatments provide a plausible explanation for the more rapid pre-vernalization shoot growth observed in response to these soil inocula. Therefore, pre-vernalization results do not particularly support the hypothesis that microbiological differences among inocula soils were affecting shoot growth during this stage. At the final harvest in both studies, inocula from all management systems reduced shoot biomass relative to the pasteurized control inoculum (Table 1). Averaged over management systems this reduction was approximately 15%. It is unlikely that this reduction resulted from nutrient differences between the pasteurized inoculum and cropping system inocula, since pasteurized inoculum soils had relatively low levels of most nutrients, despite higher biomass production (Table 2). Therefore, these results are consistent with the hypothesis that microbiological differences among inoculum soils affected post-vernalization rye growth. Shoot biomass at final harvest was different among management systems (Table 1). Inocula from 2-year rotations again produced greater shoot biomass than inocula from 4-year rotations (Table 1). For example, in Study I, inocula from the 2-year rotation treatments increased biomass by 19%, relative to 4-year treatments. The positive effect of inocula from organic systems diminished after vernalization, and had no significant effect at harvest 4 (Table 1). Again, this pattern of results is not readily explained by nutrient differences among inoculum soils (Table 2). Apparently, some non-nutrient factor differed among these inocula, and these results are consistent with the hypothesis that microbiological differences among soils from different management systems can substantially affect rye shoot growth.

Relative to the pasteurized inoculum, root biomass production was also significantly reduced by inocula from all management systems and from the prairie treatment (Table 3). However, in contrast to shoot biomass, root production was not significantly affected by inocula from management systems.

Rye cultivars differed in overall response to soil inocula from the management treatments, relative to their growth in the pasteurized control. Specifically, contrasts comparing mean shoot biomass production in management-system inocula to the pasteurized control were different among cultivars at three of four harvests in Study I and two of four harvests in Study II (Table 4). In particular, differences existed among cultivars at the fourth harvest in both studies; these were particularly pronounced in Study II.

**Table 1.** Shoot biomass averaged across three rye cultivars from soil mixtures inoculated with soils from seven management systems and one pasteurized control in two greenhouse studies (Studies I and II). The interval between harvest periods 2 and 3 was a vernalization period (days 30–126 for Study I and 32–83 for Study II).

| | Study I | | | | Study II | | | |
|---|---|---|---|---|---|---|---|---|
| | Harvest 1 | Harvest 2 | Harvest 3 | Harvest 4 | Harvest 1 | Harvest 2 | Harvest 3 | Harvest 4 |
| | Days after planting | | | | | | | |
| | 14 | 28 | 145 | 159 | 16 | 31 | 100 | 114 |
| Soil | mg plant$^{-1}$ | | | | | | | |
| 2-year Con | 31.9 | 53.2 | 165 | 280 | 32.0 | 74.3 | 141 | 202 |
| 2-year Min | 30.1 | 58.3 | 151 | 262 | 31.0 | 68.6 | 135 | 221 |
| 2-year Org | 35.2 | 62.2 | 158 | 277 | 38.2 | 90.1 | 150 | 219 |
| 4-year Con | 30.1 | 54.6 | 147 | 234 | 27.4 | 66.2 | 125 | 189 |
| 4-year Min | 27.8 | 56.7 | 149 | 229 | 24.7 | 59.5 | 108 | 166 |
| 4-year Org | 29.8 | 57.1 | 150 | 227 | 33.1 | 82.4 | 149 | 200 |
| Prairie | 30.6 | 57.1 | 171 | 279 | 33.0 | 76.5 | 132 | 195 |
| Control | 27.0 | 66.0 | 157 | 298 | 25.0 | 69.0 | 147 | 241 |
| $P>F$ | *** | ** | NS[1] | *** | *** | *** | *** | *** |
| Contrasts | | | | | | | | |
| Crop[2] versus Control | 3.85** | −9.00*** | −3.78 | −46.67*** | 6.13*** | 4.56 NS | −11.56 NS | −41.91*** |
| Con versus Min | 2.08 NS | −3.59 NS | 5.94 | 11.73 NS | 2.08 NS | 6.21** | 11.02 NS | 1.87 NS |
| Con versus Org | −1.52 NS | −5.69* | 1.62 | 5.24 NS | −5.94*** | −15.99*** | −16.53** | −14.58 NS |
| Min versus Org | −3.61** | −3.61 NS | −4.32 | −6.49 NS | −7.79*** | −22.20*** | −27.56*** | −16.44 NS |
| 2-year versus 4-year | 3.15** | 1.77 NS | 9.55 | 42.97*** | 6.52*** | 8.29*** | 14.41** | 29.07*** |
| 2-year Con versus 4-year Con | 1.78 NS | −1.42 NS | 18.43 | 45.71** | 4.56** | 8.07* | 15.82 NS | 13.36 NS |
| 2-year Min versus 4-year Min | 2.26 NS | 1.62 NS | 2.67 | 32.42 NS | 6.29*** | 9.16** | 26.27** | 54.96*** |
| 2-year Org versus 4-year Org | 5.41** | 5.12 NS | 7.55 | 50.78** | 5.13*** | 7.64* | 1.16 NS | 18.96 NS |

[1] Not significant at $P \leqslant 0.05$.

[2] Included soils from the six cropped systems [2- and 4-year conventional (Con), minimum (Min) and organic (Org) systems], but not the prairie.

* Significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

**Table 2.** Soil nutrient concentrations at the first harvest from Study II for soil mixtures inoculated with soils from seven management systems and one pasteurized control.

| Soil | Nutrient concentrations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | P | K | Ca | Mg | Na | Fe | Cu | Mn | Zn |
| | mg kg$^{-1}$ | | | | | | | | |
| 2-year Con | 6 | 44 | 1110 | 220 | 8 | 19 | 0.3 | 7 | 0.7 |
| 2-year Min | 7 | 52 | 1333 | 281 | 6 | 37 | 0.4 | 14 | 1.3 |
| 2-year Org | 22 | 79 | 1513 | 270 | 12 | 26 | 0.4 | 10 | 1.9 |
| 4-year Con | 11 | 58 | 1616 | 281 | 4 | 38 | 0.6 | 24 | 2.4 |
| 4-year Min | 9 | 42 | 1201 | 212 | 2 | 29 | 0.5 | 36 | 1.1 |
| 4-year Org | 15 | 62 | 1260 | 227 | 6 | 30 | 0.5 | 19 | 2.2 |
| Prairie | 10 | 66 | 1546 | 280 | 5 | 33 | 0.6 | 22 | 1.6 |
| Control | 7 | 25 | 691 | 134 | 7 | 21 | 0.3 | 8 | 0.9 |

In the latter study, inocula from the management systems reduced shoot biomass production more sharply in the two cultivars that had greater overall biomass production (Homil21 and Rymin; results not shown) than in the less productive cultivar Dacold (Table 4). As noted above, shoot-biomass differences at the final harvest between the pasteurized control treatment and the mean of soil inocula from the management-system treatments at the final harvest were most likely due to effects of soil microbiota, supporting our inference that the rye cultivars differed in their mean response to the presence of soil microbiota. There was no difference among cultivars in their response to the inocula from the management systems at any harvest, thus the cultivars did not show any differential sensitivity to nutrient or microbiological differences among these systems.

### *AMF colonization*

Root samples from all four harvests (from Study II) indicated that little colonization occurred prior to the third sampling date, rising to moderate levels thereafter (results from three harvests not shown). At final harvest, AMF colonization was affected by soil inoculum source (Table 5). Colonization was greater in Study I averaging 8.8%, compared with the Study II average of 5.6% (Table 5). Highest levels of colonization occurred with 2-year conventional soils, which averaged 18.7 and 7.2% colonization, and 4-year minimum soils, which averaged 12.8 and 7.5% colonization, in Studies I and II, respectively. In both studies, the lowest colonization levels were observed in inocula from organic systems, which had high P levels. Colonization levels in soils from organic systems were reduced relative to soils from conventional and minimum systems in Study I (Table 5). In Study I, 2-year rotations had higher colonization than 4-year rotations while in Study II 4-year rotations had slightly greater infection (Table 5). Colonization levels were also different among rye cultivars in Study I, where Homil21 had greater colonization levels than the other two rye cultivars (Table 6). However, no significant cultivar effects were evident in Study II where colonization rates were lower (Table 6).

**Table 3.** Root biomass averaged across three rye cultivars grown in soils from soil mixtures inoculated with soils from seven management systems and one pasteurized control at final harvest (159 days for Study I and 114 days for Study II).

| | Study I | Study II |
|---|---|---|
| Soil | mg plant$^{-1}$ | |
| 2-year Con | 109 | 158 |
| 2-year Min | 116 | 147 |
| 2-year Org | 106 | 150 |
| 4-year Con | 104 | 146 |
| 4-year Min | 106 | 149 |
| 4-year Org | 93 | 177 |
| Prairie | 116 | 113 |
| Control | 223* | 201* |

* Significantly different from all other soils at $P \leqslant 0.05$.

## Discussion

Inocula from different management-system treatments in the VICMS experiment had considerably different effects on rye shoot biomass production after vernalization. We note that our results do not definitively refute the hypothesis that differences in nutrient concentrations (or other chemical or physical factors) rather than differences in soil microbiota are the cause of the observed differences in rye growth. In fact, the different effects of inocula on pre-vernalization growth could be plausibly explained by nutrient level differences. After vernalization, however, inocula effects on growth are not well explained by nutrient differences; therefore, these effects most likely resulted from differences in some non-nutrient factor, highlighting the probable role of soil microbiological differences among inocula.

We found that soil inocula from all VICMS management systems reduced post-vernalization growth of rye. This result suggests that under field conditions, the net effect of

**Table 4.** Mean reduction in rye shoot biomass associated with soil inocula from management system treatments (i.e., difference from pasteurized control) for three rye cultivars.

| | Study I | | | | Study II | | | |
|---|---|---|---|---|---|---|---|---|
| | Harvest 1 | Harvest 2 | Harvest 3 | Harvest 4 | Harvest 1 | Harvest 2 | Harvest 3 | Harvest 4 |
| Variety | mg plant$^{-1}$ | | | | | | | |
| Dacold | 3.1 | −14.8 | −32.5 | −55.3 | 3.2 | 3.3 | −30.9 | −12.1 |
| Homil21 | 4.8 | −4.9 | 1.5 | −45.0 | 6.9 | 4.5 | −2.3 | −74.5 |
| Rymin | 3.6 | −7.3 | 19.6 | −39.7 | 8.3 | 5.9 | 1.5 | −39.2 |
| $P>F$ | * | ** | NS[1] | ** | *** | NS | NS | *** |

[1] Not significant at $P \leqslant 0.05$.
* Significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$.

soil microbiota in any of these cropping systems would be to impede rye growth, presumably due to the accumulation of some deleterious or pathogenic microbial agent. Accumulation of such sub-lethal pathogens is often suspected as a factor in yield decline in short-rotation or monoculture cropping scenarios[39]. However, previous to this study, rye had not been grown in any treatment of the VICMS experiment, and therefore it would be somewhat surprising if pathogens affecting rye occurred in all VICMS treatments. It is also possible that the observed negative effects of soil microbiota represent parasitic effects of microbes that can have important positive effects at certain growth stages. For example, AMF may be net parasites at most stages of plant growth, yet have highly beneficial effects when mycorrhizal plants encounter a variety of stress factors[40]. Likely, rye plants did not experience significant stress factors in our experiment; thus full evaluation of effects of soil microbiota will require assessment of how cover crops are affected by microbiota during periods when cover crops typically experience growth-limiting stress factors.

Our finding that soil microbiota reduce rye growth highlights the question of whether there are practical management methods that can improve soil quality for rye cover cropping by lessening negative soil microbiotic effects on rye growth. Diversification may be one such option, since there are indications that beneficial soil microbiota accumulate in more diversified cropping systems[41,42]. Our results do not support that hypothesis; we found that inocula from longer and more diversified rotations exerted more negative effects on rye than shorter rotations. These effects of rotation length on rye growth could be mediated by the size of the microbial community. A study on VICMS determined that microbial biomass was greater in the 4-year rotations compared with the 2-year rotations[32], and if rhizosphere microbial communities are correspondingly larger in longer rotations, these communities may exert a larger cost to rye plants.

**Table 5.** Arbuscular mycorrhizal fungi colonization averaged across three rye cultivars from soil mixtures inoculated with soils from seven management systems and one pasteurized at final harvest (159 days for Study I and 114 days for Study II).

| | Study I | Study II |
|---|---|---|
| Soil | % | |
| 2-year Con | 18.7 | 7.2 |
| 2-year Min | 8.5 | 3.4 |
| 2-year Org | 6.9 | 2.9 |
| 4-year Con | 5.8 | 5.8 |
| 4-year Min | 12.8 | 7.5 |
| 4-year Org | 1.9 | 5.0 |
| Prairie | 7.2 | 7.3 |
| Control | 0.5 | 0.2 |
| $P>F$ | *** | *** |
| Contrasts | | |
| Con versus Min | 0.02 NS[1] | 0.07 NS |
| Con versus Org | 2.00*** | 0.35** |
| Min versus Org | 1.60*** | 0.10 NS |
| 2-year versus 4-year | 0.77** | −0.15** |
| 2-year Con versus 4-year Con | 4.10*** | 0.08 NS |
| 2-year Min versus 4-year Min | −0.47 NS | −0.84*** |
| 2-year Org versus 4-year Org | 1.60* | −0.30* |

[1] Not significant at $P \leqslant 0.05$.
* Significant at $P < 0.05$; ** significant at $P < 0.01$; *** significant at $P < 0.001$. Analysis was conducted on arcsine $\sqrt{y}$ transformed data.

**Table 6.** Arbuscular mycorrhizal fungi colonization averaged across soils from soil mixtures inoculated with soils from seven management systems at final harvest (159 days for Study I and 114 days for Study II).

| | Study I | Study II |
|---|---|---|
| Cultivar | % | |
| Dacold | 1.5 | 4.5 |
| Homil21 | 19.0 | 6.1 |
| Rymin | 8.5 | 5.9 |
| $P>F$ | *** | NS[1] |
| Contrasts | | |
| Rymin versus Dacold | 7.0*** | 1.4 |
| Rymin versus Homil21 | −10.5*** | −0.2 |
| Homil21 versus Dacold | 17.5*** | 1.6 |

[1] Not significant at $P \leqslant 0.05$.
*** Significant at $P \leqslant 0.001$. Analysis was conducted on arcsine $\sqrt{y}$ transformed data.

We also found no evidence that organic management methods increased the beneficial effects of soil microbiota on rye growth, relative to conventional or minimum-input methods. These results indicate that while diversified rotations and high-organic matter inputs may have a variety of beneficial effects on soil health and quality[43], there is no guarantee that these management approaches will beneficially affect soil microbiotic communities in all instances.

The small sample of rye germplasm that we examined responded differently to the soil microbiota populations within each management system. Therefore, our results provide some support for the hypothesis that integration of rye cover crops into cropping systems could be improved by capitalizing on favorable interactions between rye cultivars and soil biota. A more thorough test of this possibility would require a broader sample of rye germplasm and an effort to identify situations where agronomically useful interactions occur between soil microbiota and particular rye cultivars, e.g., when stress factors are operant. We also observed variation among rye cultivars in colonization by AMF. Possibly, the more heavily colonized cultivars are more effective hosts for agronomically beneficial AMF taxa, although host effectiveness cannot be inferred from colonization level alone[44]. Given that cover crops have been shown to increase the abundance of AMF and beneficial effects of AMF on crops[12–14,17], it would be prudent to screen cover crop cultivars for AMF colonization to identify and perhaps avoid cultivars that have low AMF colonization. Rye cultivars that are highly effective hosts for AMF might improve benefits provided by rye, such as N uptake[36], during the limited period available for rye cover-crop growth in the upper Midwest. Highly effective hosts might also increase the abundance of agronomically beneficial AMF during a limited growth period compared to cultivars that are less effective hosts.

In summary, inoculum soils from different VICMS management systems had different effects on rye growth and AMF colonization. In particular, inocula from 4-year rotation treatments reduced rye biomass more strongly than inocula from 2-year rotations, possibly reflecting effects of larger microbial communities in extended rotations. Rye cultivars responded consistently to management systems but differed in respect to AMF colonization, suggesting that certain cover-crop cultivars may provide more beneficial agroecological services to cropping systems. Our results suggest that soil microbiota, selected for by specific management systems, can influence cover-crop growth and AMF colonization. Our findings also suggest the importance of further work to determine how soil microbial communities could be managed to improve integration of cover crops into cropping systems in the upper Midwest.

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# Soil fertility management for organic rice production in the Lao PDR

W. Roder[1,*], S. Schürmann[2], P. Chittanavanh[3], K. Sipaseuth[3], and M. Fernandez[4]

[1]CIP/CFC, PO Box 670, Thimphu, Bhutan.
[2]Swiss College of Agriculture, Zollikofen, Bern, Switzerland.
[3]Project for the Promotion of Organic Farming and Marketing in Lao PDR, Vientiane, Lao PDR.
[4]Project Promotion of Organic Rice from Lao PDR, Vientiane, Lao PDR.
*Corresponding author: wrjakar@druknet.bt

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## Abstract

Rice is the most important agricultural commodity of the Lao People's Democratic Republic (Lao PDR), produced largely using traditional methods with limited inputs of fertilizers and other chemicals. The country has a wide diversity in rice production systems and rice varieties, with over 3000 different varieties recorded. The rich diversity and the production environment and methods are favorable for organic rice production. Investigations were carried out to describe soil fertility conditions, management practices, opportunities and problems associated with organic production methods for rice. Soils used for rice production are mostly of low fertility, with low organic matter and N-availability. In spite of this, virtually no fertilizer inputs are used for upland rice production. Inorganic fertilizer inputs for lowland rice production have increased rapidly over the past decade, but are still below 20 kg $ha^{-1}$. The most important nutrient sources are rice straw and manure from buffalo and cattle. *Chromolaena odorata* plays an important role in nutrient cycling in upland rice systems and is sometimes added to lowland fields. In a range of fertility management studies, yield increase ranged from 2 to 89% for manure, straw or rice husk applied at modest rates (3 t $ha^{-1}$), 32–156% for modest rates of inorganic fertilizer (60 kg N $ha^{-1}$) and 36–167% for combined application of manure or crop residues with inorganic fertilizer. The response to locally produced commercial organic fertilizer was poor. The most promising inputs and strategies available to optimize yields in organic rice production systems are (1) optimizing use of locally available nutrients, mostly from manure, crop residues and weed biomass, (2) N addition through green manure and legumes growing in rotation and (3) additions of P through guano or rock-phosphate. The Lao PDR is fortunate to have substantial bat guano deposits in limestone caves. Extensive experience is available on straw and husk management for lowland systems and green manure species for upland production systems.

**Key words:** manure, rice straw, rice husks, organic fertilizer, rock-phosphate, guano, green manure species

## Introduction

Rice is by far the most important crop for the Lao People's Democratic Republic (Lao PDR), grown on more than 700,000 ha annually. Based on water management, the rice-growing areas are grouped into rainfed lowland, irrigated lowland and upland rice; each of these represents approximately 75, 10 and 15% of the total area under rice[1]. Rice yields are generally low with a national average of 3.4, 4.5 and 1.8 t $ha^{-1}$ for rainfed lowland, irrigated lowland and upland, respectively[1]. Most of the rice varieties are glutinous. Lao rice producers generally consider the absence of a market or the low market price as the main factors limiting production (Helvetas, 2005. ProRice—Phase I, 2006–2008. Project Document, Vientiane, unpublished). At the same time, the production of speciality rice and/or organic rice for export markets is often seen as a potentially promising opportunity[2]. Within the past few years, the interest for organic production and expectations from market opportunities for organic products from the Lao PDR have increased rapidly[3]. The Ministry of Agriculture and Forestry and various projects and organizations are promoting organic production methods for market production and for home consumption. Prevailing conditions favoring organic rice production generally recognized include: (1) many rainfed rice production environments are marginal with limited response to high yielding varieties and high input systems; (2) Lao rice producers presently use only limited fertilizer inputs; and (3) traditional production methods still widely used are largely organic (Helvetas, 2005. ProRice—Phase I, 2006–2008. Project Document, Vientiane, unpublished).

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In the European or North American context, organic agriculture with annual crops is mostly based on mixed farming systems with legumes in the rotation and high inputs of manure. Under European conditions, cereal grain yields from organic production systems are about 10–30% lower when compared to conventional systems. Furthermore, studies comparing organic and conventional production have generally used the same rates of N provided either through manure or compost for organic treatments or through inorganic fertilizers with or without manure for conventional treatments[4,5]. With N application rates of 100 kg and above, manure applications for organic treatments are in the range of 10–20 t ha$^{-1}$.

Soil fertility management will be a major challenge for organic rice production in the Lao PDR. The European and North American experiences will have only limited application as the Lao rice farmers will not have the benefits of a mixed farming system nor will they have access to the required quantities of manure. Substantial information on soil fertility management, the use of organic fertilizers, residue management and green manure has been generated under Lao conditions; some of these results and experiences can be directly applied for organic production. Investigations were carried out with the objectives to:

1. describe current soil fertility conditions and management practices for the major Lao rice production systems,
2. summarize experimental soil fertility management data relevant for organic rice production in Laos, and
3. describe inputs available and recommendations given for soil fertility management in organic production systems.

## Methods

### *Locally available source of inputs*

Information on existing and potential locally available sources for soil fertility management in organic agriculture was collected from the literature and contacts with input suppliers and fertilizer factories.

### *Literature review and secondary data*

Documents and information relating to fertility management in general and the use of organic inputs in particular were collected from published and unpublished sources.

### *Survey of rice producers*

An economic survey was carried out in 2004, in three districts of Champasak province in collaboration with the Provincial Agriculture Service. Formal survey questionnaires were used to collect production and economic data. For the present paper, only the cost of inputs and rice yields were used.

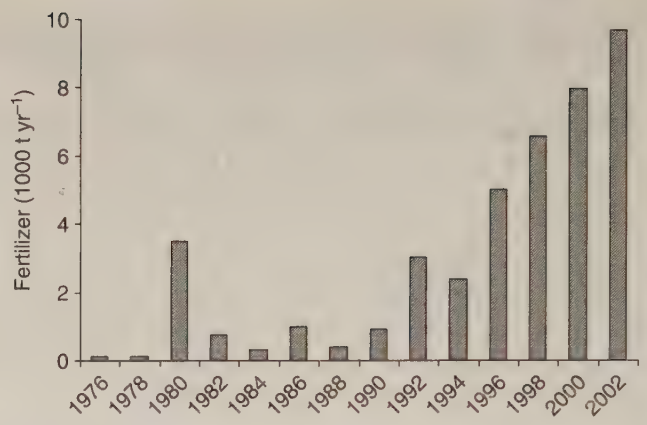


**Figure 1.** Fertilizer import (each bar represents the average of the year indicated and the year before[17]).

### *Studies by Lao-IRRI project and others*

From 1990–2002, the Lao-International Rice Research Institute (IRRI) project carried out a range of studies evaluating the effect of organic fertilizer, manure, rock-phosphate, straw applications and green manure in lowland and upland rice production systems across a range of environments[6–14]. The results available in annual reports were revisited and summarized.

### *Survey organizations recommending organic agriculture*

Information was collected from non-government organizations which recommend organic agriculture or 'clean agriculture' through informal interviews supported by questionnaires.

## Results

### *Soil fertility and current management practices for lowland rice*

Lowland rice soils in the southern part of Laos are predominantly Acrisols[15]. Typically, these soils are highly weathered, have a low inherent fertility, a low pH and a low cation-exchange capacity. Soil data (0–20 cm) indicate that 80% of the soils in the south contain less than 2% organic matter, 68% are coarse textured sand and 87% have a pH of less than 5.5. Of all the elements tested, N was the most important yield-limiting factor but the severity varied considerably between sites[15]. The second most limiting factor was P, with 71% of the sites in the south and 37% of the sites in the north responding to P application. In spite of the low fertility, using chemical fertilizer for rainfed lowland rice production is a recently introduced practice for Laos. In a survey conducted in 1996, 60% of the farmers reported that they started using fertilizer only after 1995[16]. In the past ten years, fertilizer consumption has increased rapidly (Fig. 1), but based on the FAO statistics[17] the average fertilizer consumption is still $<10$ kg ha$^{-1}$ land

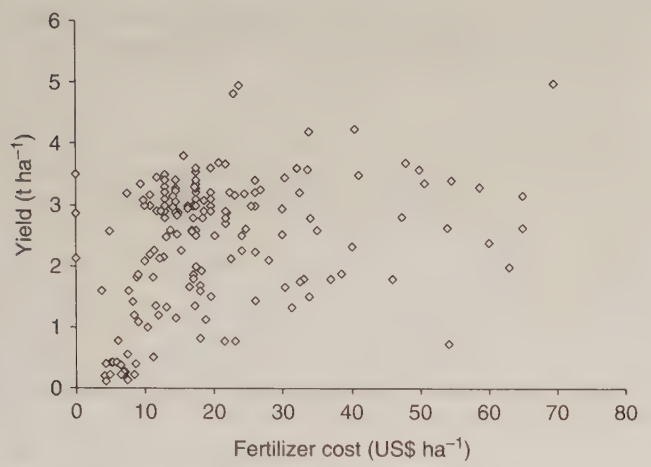


**Figure 2.** Investment in fertilizer and rice yield for rainfed rice in Kong, Sukumma and Phonethong districts (Champasak province).

cultivated. In the survey in Champasak province, only three out of 196 households surveyed used no fertilizer for rainfed rice production. There was a strong relationship between investment in fertilizer and rice yield (Fig. 2), but the data also show that there was little return for investments in fertilizer above US$20 ha$^{-1}$.

## *Soil fertility and current management practices in upland rice*

Upland soils are generally poor, mainly red–yellow, podzolic and reddish brown lateritic, leached and acidic, with low water-holding capacity[18]. Soil fertility is generally cited as a major constraint in upland rice production. Yet, extensive investigations focusing on soil-related factors that may affect rice yield failed to show a conclusive relationship between conventional soil fertility parameters and rice yield, and fertilizer applications did not show consistent results[18] (Table 1). In spite of the inconsistent response, N clearly limits rice yields. N-stress is especially likely to affect yield during the later part of the growing season as indicated by a strong relationship between leaf chlorophyll at the time of flowering and yield[18]. Application of P resulted in increased P uptake of 38% but had no consistent effect on grain yield[19]. Upland rice producers presently do not apply any fertilizer or manure. With a gradual decline in the level of organic matter because of shorter fallow cycles, it is expected that N stress may become more pronounced. For sustained upland rice production, it will be important to limit N and organic matter losses and to provide sufficient N during the critical stages of the rice crop through N-rich residues of forages/crops grown in rotation and/or appropriate fertilizers.

Various studies focused on the effect of residue management on rice yield, weed biomass and other parameters[18,20,21]. Although drought is considered a major yield constraint, no positive short-term benefits of mulching on grain yield could be demonstrated except in a study involving mulching with pigeonpea (*Cajanus cajan*) residues[22] (Table 2). Burning of crop and fallow vegetation residues consistently reduced weed biomass and made field preparation easier[21].

**Table 1.** Results of fertilizer studies in upland rice[20].

| Parameters studied | Increase in rice yield (%) |
|---|---|
| Application of N during early phase | 0–20 |
| Application of N during booting stage | 0–40 |
| Application of N after flowering | 0–70 |
| Application of N in two splits | 0–69 |
| Application of N in three splits | 0–80 |
| Application of P fertilizer | 0–15 |

**Table 2.** Effect of residue management and mulching in upland rice[20].

| Parameters studied | Effect on rice yield (%) |
|---|---|
| Mulching with rice straw | Reduction 0–50 |
| Mulching with pigeon pea residue | Increase 57 |
| Mulching with *Chromolaena odorata* (fresh) | 0 |

## *Nutrient sources for organic production*

Lao rice producers mostly rely on the production capacity of their soils. Until recently, limited quantities of nutrients were added through manure or inorganic fertilizers and, before 1980, the quantities of chemical fertilizers imported were negligible[17]. Rice producers generally do not optimize the benefits from manure and crop residues. Straw removed at harvest is often burned after threshing or used as livestock feed and only limited efforts are made to increase the quantity or quality of manure produced.

The most important nutrient sources for organic rice production will be manure, crop residues and compost made from materials available at village level. Although most of these nutrients are already used, there are opportunities to improve the utilization and reduce losses, especially for N. The weed *Chromolaena odorata* plays a special role in nutrient cycling, especially in upland environments[23]. Occasionally, biomass of this species is also used by lowland rice producers.

Cattle and buffalo are important sources of plant nutrients and agents in accelerating nutrient cycling. To some extent, they also serve as a vehicle for transferring nutrients from fallow land and forest to the rice fields. The available statistics indicate that there are 1.8 head cattle and 1.6 buffalo per hectare of rice. Lowland rice farmers are more likely to have buffalo, while upland rice farmers are more likely to have cattle. Traditionally, buffalo are used for field preparation in lowland systems. Lowland rice farmers are, however, gradually replacing buffalo with tractors ('Tractors versus buffaloes', Vientiane

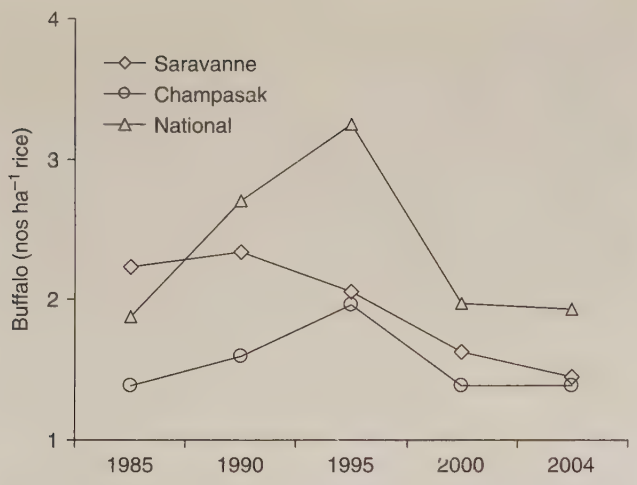


**Figure 3.** Buffalo density (numbers per hectare of lowland rice) given for the national level and two major rice-producing provinces Saravanne and Champasak[1].

Times, July 12, 2005) and there is a tendency of decreasing livestock numbers (Fig. 3). Adding micro-organisms to hasten decomposition of organic matter is widely recommended for compost making, especially a technology known as EM (effective micro-organism). This technology may accelerate nutrient cycling and availability but it does not bring additional nutrients to a system.

Commercially available sources of nutrients that are permitted for organic agriculture are biofertilizers, bat guano and rock-phosphate. In the late 1990s, the government of Lao PDR established ten biofertilizer factories[24], with a production potential of 88,400 t yr$^{-1}$. In the year 2004, these factories produced about 20,000 t. All factories use similar raw material, with peat from a lake being the main ingredient (60–80%). A range of other products such as slaughterhouse by-products, by-products from beer, sugar and tobacco processing, rock-phosphate and guano are added and composted together with the peat (Manager, Dong Xiengdy factory, Vientiane, personal communication, 2005). All components are mixed, a solution of micro-organisms is sprayed on and then the mixture is fermented for 20–30 days. Analytical data are available for five factories (Table 3). Because of limited crop response, farmers have shown little interest and five factories stopped production in 2005 due to limited markets. Furthermore, according to the International Federation of Organic Agriculture Movements (IFOAM) standards, fertilizers with peat as a base would be allowed for potted plants only[25].

Laos is very fortunate to have extensive deposits of bat guano in limestone caves (W. Roder, P. Chittanavanh, K. Sipaseuth, and M. Fernandez, 2005. Inputs available for organic farming, PROFIL/DoA/Helvetas, Vientiane, unpublished). It is quite likely that the deposits referred to as 'rock-phosphate' in some documents are actually also mineralized guano. The P and N contents of the guano deposits vary (Table 4). The mineral content is largely

**Table 3.** Nitrogen and phosphorus composition of biofertilizers[24].

| | Content (%) | |
|---|---|---|
| **Factories** | **N** | **$P_2O_5$** |
| Dong Xiengdy | 1.5 | 2 |
| Xiengda | 2.8 | 8.3 |
| Maliny | 1.5 | 5 |
| Savannakhet | 3 | 5 |
| Champasack-46 | 1.5 | 1.5 |

**Table 4.** Nitrogen and phosphorus content of five guano samples originating from Khammuone Province.

| | Content (%) | |
|---|---|---|
| **Nutrient** | **Average** | **Range** |
| Nitrogen | 0.12 | 0.02–0.35 |
| Phosphorus | 3.6 | 0.7–5.7 |

dependent on the age and the stage of mineralization. The milled guano is presently sold for about US$70 t$^{-1}$. At this price, it is a cheaper source of P than single or triple superphosphate. Although guano is accepted as an input for organic production, it is important to emphasize that guano is a non-renewable resource, as rapid exploitation will lead to its depletion.

## *Experiences with inputs permitted in organic agriculture*

**Effects of manure and crop residues for lowland rice.** The Lao-IRRI project has evaluated effects of manure, straw or rice husk over a wide range of environments[8–14] (Table 5). These studies showed that manure, straw or rice husk applied at modest rates can increase yields by 10–80%, while modest rates of inorganic fertilizer applied alone can increase yields by 30–150%. In all experiments, the yield increase was consistently higher with inorganic fertilizers and highest when inorganic fertilizer was combined with manure application. The residual effect of repeated manure applications was not apparent. In these studies, the nutrient quantities applied through manure or crop residues were, however, always below the nutrient quantities applied through inorganic fertilizers.

Current soil fertility management recommendations of the government extension system emphasize the benefits of using straw and rice husk. Rice farmers are, however, often reluctant to follow these recommendations. Farmers' limited interest in utilizing straw and manure are influenced by the difficulties in collecting and transporting manure or straw and in field preparation when using straw. Furthermore, crop yellowing is often observed during the first week following transplanting when straw is incorporated, due to N immobilization.

**Table 5.** Effect of N fertilizer, manure, rice straw and rice husk on rice yields.

| Year/season | Fertilizer (t ha$^{-1}$) N | M | S | H | Yield (t ha$^{-1}$) | Yield increase (%) N | M | S | H | N+M | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Repeated over years on same plot (residual effects for 2nd and 3rd year) | | | | | | | | | | | |
| Saravane district (Saravane) and Phonethong district (Champasack) | | | | | | | | | | | |
| 1st year | 0.06 | 2 | 2 | 2 | 1.35 | 121 | 48 | 48 | 50 | 182 | 9 |
| 2nd year | 0.06 | 2 | 2 | 2 | 1.21 | 156 | 69 | 68 | 69 | 192 | 10 |
| 3rd year | 0.06 | 2 | 2 | 2 | 1.92 | 67 | 61 | 66 | 60 | 103 | 11 |
| 4th year[1] | 0.06 | 2 | 2 | 2 | 1.57 | 98 | 89 | 75 | 59 | 167 | 12 |
| Xiengkho district (Houaphanh), Vapi district (Saravane) and Peng district (Xayabouli) | | | | | | | | | | | |
| 1st season | 0.06 | 2 | – | – | 1.90 | 84 | 8 | – | – | 98 | 12 |
| 2nd season | 0.06 | 4 | – | – | 2.63 | 44 | 19 | – | – | 58 | 13 |
| New sites (no residual effects) | | | | | | | | | | | |
| | 0.06 | 5.2 | – | 1.3 | 2.41 | 41 | 25 | – | 15 | 67 | 8 |
| | 0.06 | 2 | – | 2 | 2.70 | 32 | 18 | – | 19 | 48 | 10 |
| | 0.06 | 2 | – | – | 3.24 | 32 | 2 | – | – | 36 | 11 |

N = inorganic N fertilizer (t N); M = manure; S = rice straw; H = rice husk (M, S and H quantities in t ha$^{-1}$ based on dry weight).
[1] Phonethong district only.

**Table 6.** Effect of commercial organic fertilizers on rice yields.

| Locations (numbers) | Seasons | Fertilizer (t ha$^{-1}$) N | COF | Yield (t ha$^{-1}$) | Yield increase (%) N | COF | Reference |
|---|---|---|---|---|---|---|---|
| 2 | 2 | 0.06 | 1.0 | 2.0 | 52 | 18 | 9,10 |
| 5 | 3–4 | 0.06 | 1.0 | 2.0 | 66 | 20 | 14 |
| 12 | 1 | 0.07 | 2.0 | 2.79 | 50 | 12 | 13 |

N = inorganic N fertilizer in (t N).
COF = commercial organic fertilizer in t of fertilizer (1.5–3% N).

**Commercially available organic fertilizers and rock-phosphate.** Data are available from studies with commercially available biofertilizer across a wide range of locations (Table 6). One of these studies was repeated over four rice crops. The response to the biofertilizer is generally poor. A recent FAO project for the promotion of organic fertilizers tested the biofertilizer across a wide range of rice production environments with application rates of 600 kg ha$^{-1}$ but no yield response was observed[24]. This study concluded that the low nutrient content of the biofertilizers required high application rates, making the fertilizer too expensive.

The results of the limited studies with rock-phosphate (imported from Kunming, People's Republic of China) are very promising (Table 7). The response to rock-phosphate was generally better than to triple superphosphate. Unfortunately, the locally available guano was not included in these studies.

## *Experiences with green manure species*

Green manure species have been widely tested and recommended for all rice-growing environments[7,18]. In spite of this, none of the species/systems recommended have been adopted on a wider scale. Both lowland and upland rice farmers sometimes use grain legumes in rotation with rice, especially *Vigna* species and peanuts.

**Lowland rice environments.** Green manure species tested included *Aeschynomene afraspera*, *Crotalaria juncea*, *Sesbania aculeate*, *S. rostrata*, *Vigna radiata* and *V. unguiculata*[7]. Based on studies repeated over locations and years, it was found that *C. juncea* and *V. radiata* are unsuitable for periodically saturated soil conditions that are a normal feature in rainfed lowland environments. *S. rostrata* was promising but it could not be recommended because it is a host of the root-knot nematode (*Meloidogyne graminicola*). In order to have optimum N-fixation, green manure legumes generally require higher P levels than rice. In a study across three locations, the dry matter production of *S. rostrata* was 0.6, 2.4 and 2.9 t ha$^{-1}$ with 0, 30 and 60 kg P ha$^{-1}$, respectively[6]. Phosphorus is likely to be a major limitation for using green manure in some lowland rice-growing environments.

**Upland rice environments.** A wide range of legumes have been tested for fallow and/or soil fertility management in upland rice production systems. Already in 1930,

**Table 7.** Effect of rock-phosphate on rice yields.

| Location[1] | Years after 1st application | Yield ($t\,ha^{-1}$) | Yield increase (%) | | Reference |
|---|---|---|---|---|---|
| | | | TSP[2] | Rock P[3] | |
| Vientiane | 0 | 3.23 | 6 | 14 | 8 |
| Vientiane | 1 | 3.5 | 8 | 24 | 9 |
| Vientiane | 2 | 2 | 10 | 10 | 10 |
| Houaphanh | 0 | 4.33 | 14 | 3 | 9 |
| Houaphanh | 1 | 3.2 | 28 | 25 | 10 |
| Houaphanh | 2 | 3.3 | 16 | 35 | 11 |

[1] Fertilizer application was repeated yearly for Vientiane. For Houaphanh, the fertilizer was applied in the first year only.
[2] Triple superphosphate applied at the rate of 60 kg $P_2O_5$ $ha^{-1}$.
[3] Rock-phosphate, applied at the rate of 320 kg $P_2O_5$.

Goubeaux[26] worked with 46 legume species. The presence of *Mimosa invisa*, a serious weed in some isolated upland areas, is an unpleasant testimony of those activities. The main species promoted by various agencies for fallow improvement over the past two decades were *Leucaena leucocephala*, *Gliricidia sepium*, pigeon pea and *Calliandra calothyrsus*. In addition, the following species were recommended based on work carried out by the Lao-IRRI project: *Arachis pintoi*, *Calopogonium caeruleum*, *Centrosema pubescens*, *Crotalaria anagyroides*, *Lablab purpureus*, *Leucaena diversifolia*, *Stylosanthes guianensis*, *Pueraria phaseoloides* and *Mucuna cochinchinensis*[18]. Most of the species evaluated have multiple uses, including food, fodder and/or fuel. Pigeonpea received special attention, with activities focusing on: collection and testing of local and introduced cultivars, establishment methods, rotation effects, residue management and weed suppression[22]. Important findings from studies carried out between 1991 and 1999 over a range of locations include:

- replacing fallow vegetation with legumes had generally no effect on rice yield and weed biomass[18];
- interplanting rice with shrubby perennial legumes (pigeon pea, *L. leucocephala* and *C. anagyroides*) can add to total biomass produced and suppress weeds during the dry season fallow[20];
- *A. pintoi* is not suitable for live mulch systems due to competition for moisture[27];
- pigeon pea, *C. anagyroides* and *S. guianensis* are the most promising legume species for upland rice systems[18];
- residue management is a critical issue, and for most species tested, field preparation without burning was difficult[28];
- intercropping with *L. leucocephala* reduced rice yield in dry years[20]; and
- most legume species can be easily established by broad-casting seed immediately after the last rice weeding or by mixing seed with rice seed and dibbling together. The latter can, however, affect rice yield negatively[29].

**Table 8.** Technologies recommended for soil fertility management.

| Technology recommended | Number of agencies[1] ($n = 11$) | |
|---|---|---|
| | Recommending technology | Documented results |
| Stop using inorganic chemicals | 10 | 0 |
| Use compost | 8 | 0 |
| EM for composting and pest management | 2 | 1 |
| Bio-extracts for pest management | 3 | 0 |

[1] Agencies recommending technology.
EM, effective micro-organisms.

## *Recommendations given for soil fertility management*

Of all the organizations/projects visited, only two promote 'organic production methods' as per international definitions[25]. All other projects/organizations promote 'chemical free agriculture'. The main recommendation given to the producer is 'stop using chemicals' (Table 8). Some organizations have no recommendation for soil fertility and pest management. Others recommend the use of compost. Bio-extract, effective micro-organisms and biocontrol are the only other recommendations given. Surprisingly, none of the organizations promotes the use of green manure.

Except for effective micro-organisms, no information was found documenting systematic evaluation of the recommendations under Lao conditions. Similarly, no reliable information is available on the adoption rate for any of the recommended technologies. The limited availability of plant nutrients or sources of organic fertilizers (especially manure) was, however, recognized by two organizations as the main problem.

### *Implications for organic rice production*

Lao farmers produce rice under marginal conditions with low yields and low yield potentials. This is often considered as an advantage for organic production as response to inorganic fertilizers is limited. Yet, soil fertility will be the most important constraint for organic rice production. In order for rice producers to benefit from organic production, practical, effective and economic soil management strategies have to be available. Strategies and recommendations need to be based on local soil conditions, existing management practices and locally available nutrient sources. Unlike in Europe or Northern America, the farmers have to develop soil fertility management strategies without having the benefits of a traditional mixed cropping system with legumes or a system with large volumes of organic manure available. Depending on the evolving production system, it may be necessary to import certain inputs, especially phosphate.

The most promising technologies available to optimize yields in organic systems include:

- optimize the use of locally available nutrients, mostly from manure, crop residues and weed biomass,
- add N to the system through green manure and legumes growing in rotation, and
- add P through guano or rock-phosphate.

Through optimal management of these nutrient sources, it will be possible to maintain or even improve present rice yields in most situations. Producers may require support in the supply of inputs (seed of green manure species, guano and rock-phosphate), marketing of new products (pulses grown in rotation and livestock products) and the development of appropriate management strategies.

Research, advisory services and other agencies making recommendations for soil fertility management in organic production systems need to be keenly aware that:

- Constant efforts have to be made to minimize confusion about the meaning of 'organic agriculture'. Until recently, most agriculture in Lao PDR was organic, yet the idea of organic agriculture is introduced as a 'new concept' with a wide range of interpretations. This has resulted in much confusion and misunderstandings.
- The principles of soil fertility management are the same for organic and conventional systems. Plants do remove nutrients from the soil, which have to be replaced.
- When developing/recommending soil fertility management strategies, it will be important to always be cautious about additional labor or investments.

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# Profitability of coupled potato and dairy farms in Maine

Aaron K. Hoshide*, Timothy J. Dalton, and Stewart N. Smith

Department of Resource Economics and Policy, University of Maine, Orono, ME, USA.
*Corresponding author: aaron.hoshide@umit.maine.edu

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## Abstract

After decades of farm specialization, re-integrating crop and livestock farming systems is being reconsidered as a key step toward sustainable agriculture. The relative profitability of Maine farms integrating crops and livestock is compared to non-integrated or conventional farms. Crop and livestock integration in Maine occurs through either diversified on-farm integration or, more commonly, through coupled interactions between specialized crop and livestock producers. Potato and dairy systems coupled for only 2 years (short-term) had greater profitability compared to conventional systems. Profitability increased in the short term in two ways. First, potato farms grew more of their primary cash crop. Secondly, dairy farms expanded cow numbers, increasing profitability assuming increasing returns to scale. Coupled systems integrated for more than 10 years (long-term) had more favorable profitability than short-term couplers since greater manure-nutrient credits were taken for potatoes and silage corn. The advantages of potato–dairy integration were even greater if potato yields increased in the long term, as suggested by long-term rotation plot studies in Maine. Even if coupling is more profitable than non-integrated systems, it requires that farms be in close proximity and for farmers to have adequate working relationships and management skills. Despite these challenges to re-integrating crops and livestock, short- and long-term economic benefits may encourage farmers in appropriate areas to consider coupling with other producers.

**Key words:** crop and livestock integration, dairy, enterprise budgets, Maine, net farm income, potato, profitability, whole-farm budgets

## Introduction

In Maine and elsewhere, cash field crops and livestock were historically integrated, usually being produced on the same farm. Field crops were typically fed to farm livestock and manure was spread on the farm's land base. Over time, however, farms have become increasingly industrialized and specialized, focusing exclusively on either crop or livestock production. Mechanization and fertilizers have eliminated the need for livestock and livestock manure on crop farms[1]. Farm specialization on single commodities has reduced the prevalence of crops and livestock integrated on the same farm. It has also made integration between specialized farms (inter-farm coupling) challenging as both crop and livestock industries have become increasingly concentrated in certain regions.

Integrated farming systems tend to have greater crop diversity[2] combined with more prevalent livestock[3] and have numerous environmental and economic benefits. Crop and livestock integration allows more efficient nutrient cycling, which can improve nutrient conservation. On the crop side, reliance on purchased fertilizers can be reduced with increased nutrient cycling from decomposing organic matter such as manure[4]. On the livestock side, tighter nutrient cycles can reduce nutrient run-off and subsequent pollution of watersheds[5]. Nutrient loading from agricultural systems can also decrease wild species diversity[6].

At the individual farm level, prior research has focused on the benefits and challenges of crop and livestock integration occurring on the same farm (on-farm), rather than between two specialized producers. Benefits included improved profitability[7], reduced input use and more even distribution of production activities[8], diversification, and risk reduction. Challenges of integrated crop and livestock systems included tradition and livestock transportation[9], increased management complexity and market availability[10], greater potential for crop diseases, government policies and marketing organizations[11], as well as vertical coordination[12].

Several Maine potato and dairy farms have addressed these challenges with crop and livestock integration,

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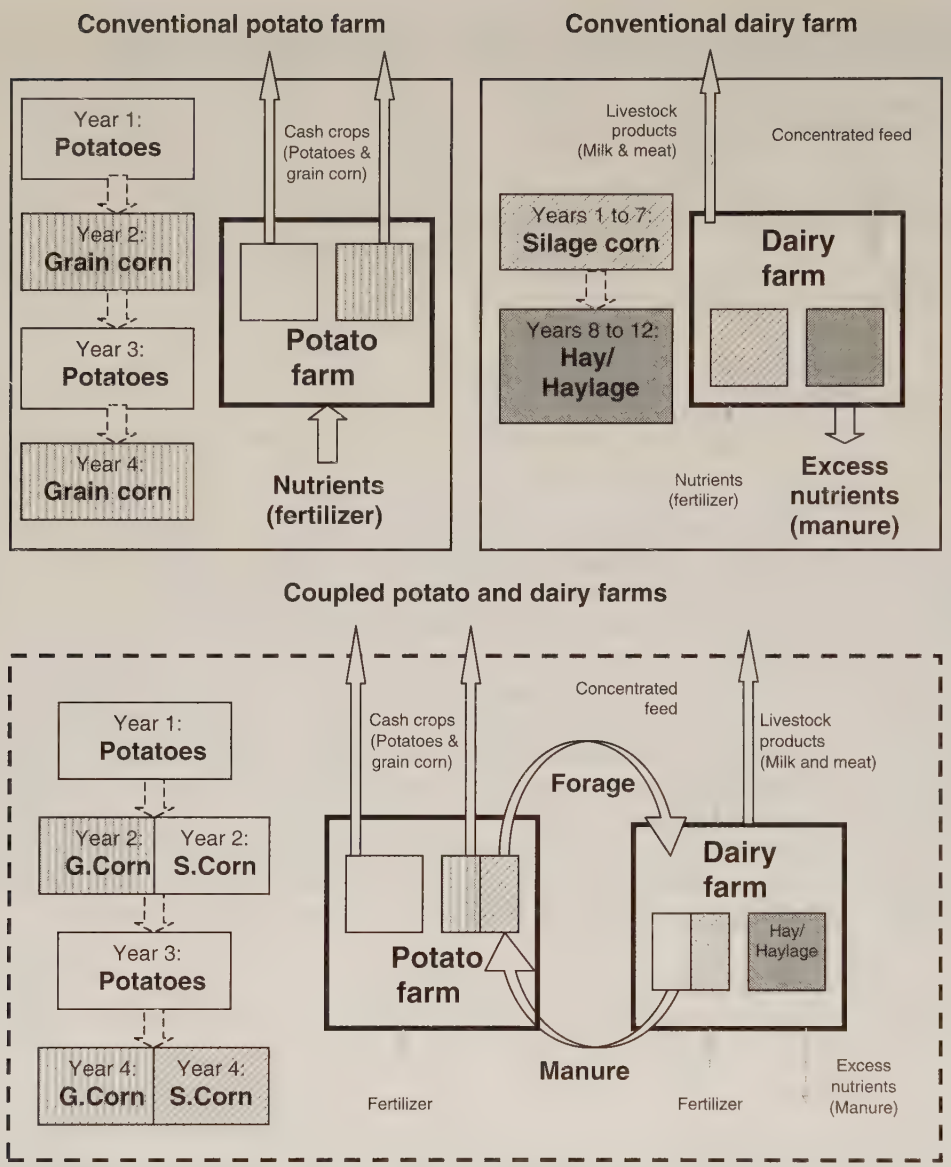


**Figure 1.** Conventional and coupled potato and dairy farm crop management.

realizing the benefits of integrating while still continuing their specialized operations. This has generated interest in the potential for coupling crop and livestock systems to improve profitability and to encourage tighter nutrient cycling. Both coupled and on-farm integration involves application of manure on cropland used for production of cash field crops, livestock feed, and/or mixed vegetables. 'Inter-farm coupling' or 'coupled' describes specialized crop and livestock operations integrating livestock with crops by exchanging livestock feed for manure as well as the land used to produce cash crops and livestock feed, while conventional (non-integrated) farms do not participate in such exchanges (Fig. 1).

The objective of our research was to better quantify the economic benefits of coupled potato and dairy farms in Maine using representative budgets. Interviews with cooperating farms and agronomic results for potato systems amended with manure suggested agronomic and socio-economic benefits to coupling. Cited benefits included increased area for cash crop production, reduced fertilizer use, increased crop yields and quality, improved soil quality, options for herd expansion, and enhanced management skills from interaction with another producer. However, integrated systems may be more costly during transition to these systems due to the increased management time spent coordinating integration with another farmer[13].

Coupled farms should be more profitable compared to conventional, non-integrated farms if coupling allows potato and dairy farms to expand. Profitability may also be improved by lower fertilizer costs if nutrient credits are taken for applied manure. Additionally, inter-farm coupling may be more profitable if crop yields are increased from integration. For coupled potato farms, higher yields are expected over time, especially in dry years, based upon the results of the Maine Potato Ecosystem Project summarized by Porter and McBurnie[14] and Gallandt et al.[15]. However,

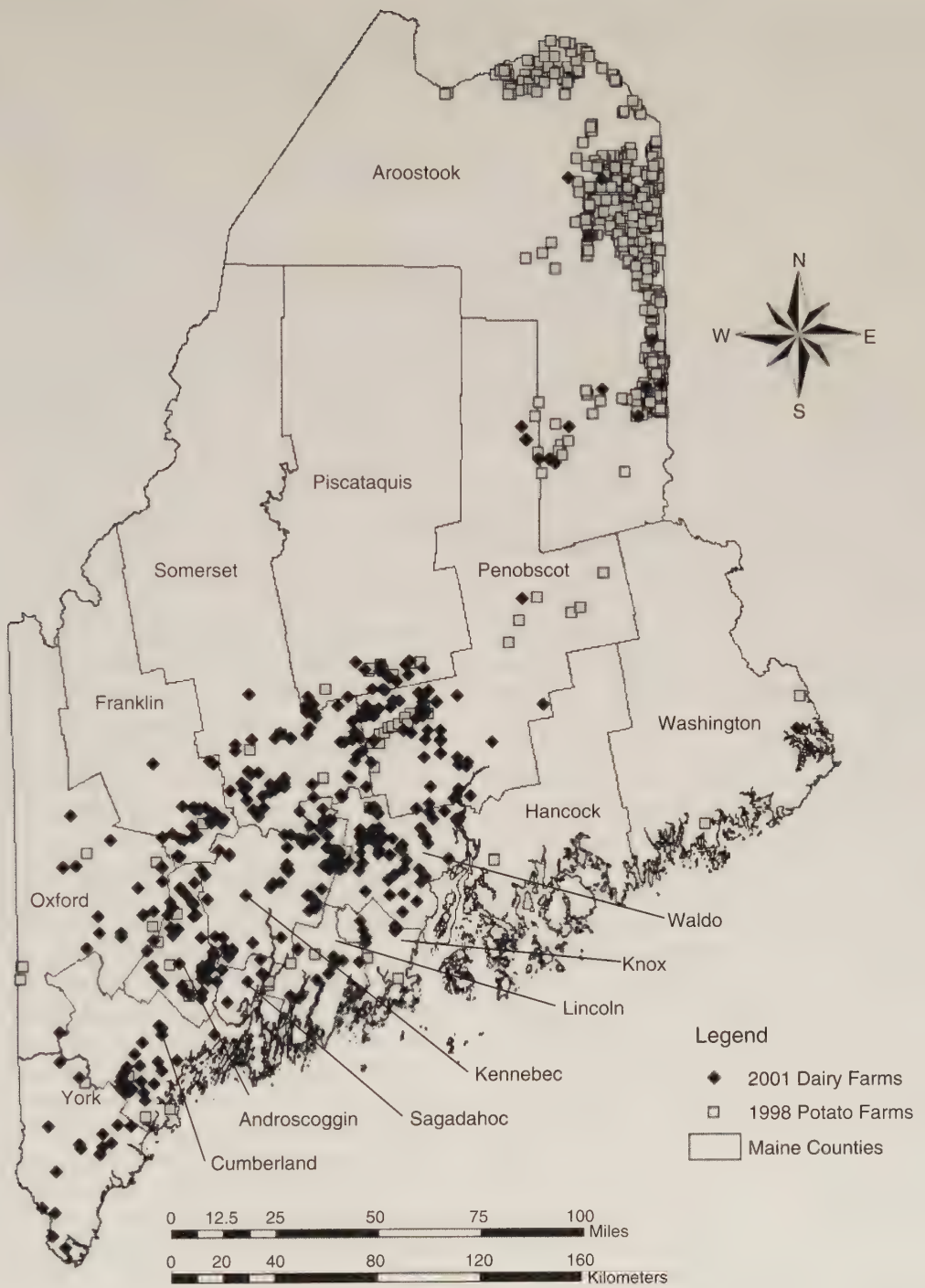


**Figure 2.** Maine potato farms in 1998 and dairy farms in 2001. Farms were plotted using farmer addresses and may not represent actual farm centers.

higher soil moisture from manure may encourage tuber diseases such as powdery scab[16], which may reduce marketable potato yield.

## Materials and Methods

### *Selection of cooperating producers*

In Maine, potato farms are concentrated in Aroostook county while the bulk of the dairy industry is in central and south-central Maine (Fig. 2). Farm numbers have decreased for both potato and dairy farms in Maine from 1964 to 1997. Annual potato production was reduced from 1,598,965 to 884,073 Mt during this time[17]. Milk production has been more variable, declining slightly from about 299,371 to 296,649 Mt from 1965 to 2001[18].

Of the 495 potato and 437 dairy farms shown in Figure 2, Maine extension educators recommended 26 cooperating potato and dairy producers for participation in this project. Cooperating producers were categorized as on-farm integrated, coupled, and potential integrators. Potential

**Table 1.** Division of production responsibilities and asset ownership for coupled farms.

| Activities | Coupled farm types | | |
|---|---|---|---|
| | **Land (L)** | **Land/Feed (LF)** | **Land/Feed/Input (LFI)** |
| Operations | | | |
| Grows and harvests potatoes | Potato | Potato | Potato/Dairy |
| Grows and harvests forage crops | Dairy | Potato | Potato/Dairy |
| Grows concentrates[1] | None | None | None |
| Spreads dairy manure | Dairy | Potato | Potato/Dairy |
| Purchases concentrates | Dairy | Dairy | Dairy |
| Manages dairy herd | Dairy | Dairy | Dairy |
| Ownership | | | |
| Potato production equipment | Potato | Potato | Potato |
| Forage production equipment | Dairy | Potato | Potato/Dairy |
| Manure spreading equipment | Dairy | Dairy | Potato/Dairy |
| Manure storages | Dairy | Dairy | Dairy |
| Livestock feed storages | Dairy | Dairy | Potato/Dairy |
| Potato and corn cropland | Potato/Dairy | Potato/Dairy | Potato/Dairy |

[1] According to Dalton and Bragg (2003), Maine dairy farms do not typically grow crops used for concentrated feed.

integrators were considering or experimented with integration in the past. On-farm integrators were diversified dairy operations or a potato farm with a livestock component. Coupled farms were two or more specialized crop and livestock farms that exchanged some combination of land, feed, and other inputs.

Enterprise production operations and asset ownership for three types of inter-farm coupling are listed in Table 1. The relationship between coupled crop and livestock farms can evolve from simple exchanging of cropland (land-coupled) to more complex arrangements where feed is exchanged (land/feed-coupled) or production inputs such as labor, fertilizer, and equipment (land/feed/input-coupled) are shared. This study focused on land-coupled and land/feed-coupled farm types common in central Maine. Although two pairs of coupled farms in central Maine were land/feed/input-coupled, this case was not analyzed due to the many ways that production inputs can be shared. Coupled potato and dairy farms were close together, typically having fields within 10 miles of the other coupler(s).

For land-coupled farms, it was assumed that silage corn grown on potato farmland was managed entirely by the dairy farm in a land swap. Thus the potato farm paid no production costs for silage corn. The dairy farm covered the costs of forage storage and manure-spreading. Land/feed-coupled farms also swapped land and it was assumed that the potato farm grew forages for sale to the coupled dairy farm at typical market prices (Table 2). In this coupling, the dairy farm provided forage and manure storages as well as the manure-spreading equipment. The potato farm paid for all other crop production costs.

Production characteristics of cooperating producers were previously summarized[19]. Potential integrators accounted for four of the 26 cooperating farms. Of the remaining 22 farms, 15 coupled farms and four on-farm integrators provided enough data for budgets. Three farms did not provide enough economic data for representative budgets. Production data from the 15 coupled farms were used to construct different scales of representative synthetic budgets. Two pairs of cooperating farms were land/feed-coupled, selling and purchasing forages slightly below market prices. In both instances, the land/feed-coupled dairy farm conducted some crop production operations. The remaining cooperating farms were land-coupled.

### *Representative farms and budgets*

Representative whole-farm and crop enterprise budgets were constructed for conventional (non-integrated) and coupled (integrated) farms in central Maine. Potato and dairy budgets varied by size class (small and large) and integration type (land-coupled and land/feed-coupled). Both integrated and non-integrated representative budgets were based on previous studies of the Maine potato[20,21] and dairy[22] industries in addition to data collected during face-to-face interviews with cooperating farmers. Farm data were based on the 2001 calendar year. Production assumptions used to derive representative budgets were based on the most common practices of cooperating farms. The combined profitability of coupled and conventional systems was also compared.

Conventional and coupled potato farms raised potatoes and corn in a 2 year rotation (Fig. 1). Potato budgets represented non-irrigated production utilized for potato chip processing. Typical central Maine marketable potato yields of 26.9 Mt $ha^{-1}$ were from an agronomist used by many cooperating potato growers (L. Titus, personal communication, 2003). Potato yields were initially assumed to be the same for coupled and conventional since research plots in northern Maine have shown manure amendment may increase (moisture retention) or decrease (disease) marketable potato yield. From 1991 to 2003, the marketable yield response for potatoes from manure amendment

**Table 2.** Enterprise budget crop yields and prices and farm hectares.

| | | | Potato farm (ha)[2] | | | | | | Dairy farm (ha)[2] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Conv. | | L-Coup. | | LF-Coup. | | Conv. and L-Coup. | | LF-Coup. |
| Crop | Yield (Mt ha$^{-1}$)[1] | Price ($ Mt$^{-1}$) | S | L | S | L | S | L | S | L | S and L |
| Potato | 26.9 | $151.68 | 65 | 130 | 85 | 195 | 85 | 195 | – | – | – |
| Grain corn | 6.3 | $98.33 | 65 | 130 | 45 | 65 | 45 | 65 | – | – | – |
| Silage corn | 33.6 | $27.56 | – | – | – | – | 40 | 130 | 40 | 130 | – |
| Dry hay[3] | 7.8 | $71.21 | – | – | – | – | 30 | – | 30 | – | – |
| Haylage[4] | 13.5 | $35.94 | – | – | – | – | – | 80 | – | 80 | – |

[1] Forage yields per hectare shown as harvested metric tons (Mt) and not Mt of dry matter.
[2] Farm hectares were operated crop hectares, not owned crop hectares. S, small; L, large.
[3] For small coupled farms, dry hay was harvested as a first cut (1.9 Mt) of round (454 kg) bales and a second cut (1.3 Mt) of square (18 kg) bales. Round and square bales used surveyed prices of $22.50 and $1.88 per bale respectively, and may not reflect current market prices.
[4] For large coupled farms, a first cut (3.3 Mt) of haylage and a second cut (2.2 Mt) consisting of 90% haylage and 10% square bales (for calves) were harvested. Haylage sold for $33 Mt$^{-1}$.

ranged from −13 to 33% with an average response of about 6% (G. Porter, personal communication, 2004).

Land/feed-coupled potato farms and land-coupled dairy farms grew silage corn and dry hay or haylage in a long-term rotation. Land/feed-coupled dairy farms did not raise any crops, focusing instead on milk production. Dairy farms purchased all concentrated feed. Crop yields and prices (Table 2) and nitrogen, phosphorus, and potassium applied as manure and fertilizer for each crop were typical for cooperating farmers in central Maine (Table 3). Coupled and conventional farms had the same transport costs for manure and forage since it was assumed fields for both types of farms were within 10 miles of the dairy farm.

Integrators were classified as short-term and long-term. Short-term integrators started coupling within the past 2 years. No reduction in chemical fertilizer use for potatoes and silage corn was observed and increased crop yields were unlikely. Long-term integrators had been coupled for more than 10 years. Potatoes and silage corn both received manure-nutrient credits. Manure-nutrient credits were reductions in fertilizer use from manure only and not from crops grown previously in the rotation.

Manure was not applied to potatoes and grain corn. Instead, manure was typically applied in the spring to silage corn during the coupled rotation year. Short-term coupled potato farms took no manure-nutrient credit for potatoes. For long-term couplers, starter fertilizer on potatoes was reduced amounting to a 61% reduction in nitrogen and a 73% reduction in both phosphorus and potassium compared to conventional applications. Application of 46-0-0 side-dressed fertilizer on potatoes was reduced by about 37% under long-term coupling (Table 3). Fertilizer was not reduced for silage corn in the short term, while a 20% manure-nutrient credit was taken in the long term. Conventional and coupled fertilization was the same for both hay and haylage, which were top dressed prior to first cut with manure applied during mid-summer.

A whole-farm budget represents all crop and/or livestock operations managed by a farm and can be used to compare profitability between different farm plans[23]. An enterprise budget shows the profitability of a single crop or livestock commodity produced by a farm. Enterprise budgets show gross income from the enterprise, production costs, net farm income, and return over variable costs and can be used for break-even analysis. In this study, potato whole-farm budgets included a potato enterprise with a rotation crop or crops. Dairy whole-farm budgets included silage corn and dry hay or haylage enterprises in addition to fluid milk.

Enterprise budget revenues used typical marketable yields and prices. Quantities and costs for inputs and outputs were based on data collected from cooperating farmers. Farm operating costs were seed, fertilizer, lime, chemicals, labor, fuel and oil, maintenance, supplies, insurance, miscellaneous costs, and interest. Ownership costs included depreciation, interest, tax and insurance on farm equipment, buildings, and land. Equipment costs shared by two or more crops were weighted based on total seasonal equipment operation time. Return over variable costs (ROVC) equals total farm revenue minus operating costs, while net farm income (NFI) is farm revenue minus both operating and ownership costs.

Both family and hired labor were used. However, family labor was not entered as an explicit cost due to lack of these data for potato farms. Thus returns to family labor were captured in net farm income, and the labor expense shown was only hired labor for both potato and dairy farm budgets. It was assumed that 25% of both potato and dairy farmland was rented. Budgets were checked with Farm Credit of Maine's 2000 data for dairy[24] and 2001 data for potatoes (S. Kenney, personal communication, 2003). Potato enterprise budgets were also compared with a previous study of potato rotations in Aroostook county[25]. Enterprise budgets for grain corn, silage corn, dry hay, and haylage were verified against existing budgets[26].

## Representative budget results

### *Potato farms*

Whole-farm budget ROVC and NFI per hectare of owned cropland was greater for coupled compared to conventional

**Table 3.** Manure, fertilizer, and nutrient applications and fertilizer cost for conventional and coupled farms.

| Farm | | | | Manure applied per hectare[1] | Fertilizer | | | Nutrients applied as (kg ha$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | --Manure-- | | | --Fertilizer-- | | | --Total-- | | |
| Type | Industry | Size | Crop | | Type (analysis) | Applied (kg ha$^{-1}$) | Cost ($ Mt$^{-1}$) | N | P | K | N | P | K | N | P | K |
| Conventional | Potato | S and L | Potato | – | Potato blend (10-10-10) | 1349 | $231 | – | – | – | 135 | 135 | 135 | 200 | 135 | 135 |
| | | | | | Side dress[2] (46-0-0) | 141 | $254 | – | – | – | 65 | – | – | | | |
| | | | Grain corn | – | Gr. corn starter (16-20-0) | 303 | $243 | – | – | – | 48 | 61 | – | 161 | 61 | 87 |
| | | | | | Side dress[2] (46-0-0) | 247 | $254 | – | – | – | 113 | – | – | | | |
| | | | | | Muriate of potash[2] (0-0-60) | 146 | $176 | – | – | – | – | – | 87 | | | |
| | Dairy | S | Silage corn | 20 Mt | Side dress (46-0-0) | 140 | $254 | 185 | 46 | 166 | 65 | – | – | 250 | 46 | 166 |
| | | | Hay | 11 Mt | Top dress (46-0-0) | 112 | $254 | 103 | 26 | 92 | 52 | – | – | 155 | 26 | 92 |
| | | L | Silage corn | 20,820 l | Side dress (46-0-0) | 140 | $254 | 156 | 93 | 127 | 65 | – | – | 221 | 93 | 127 |
| | | | Haylage | 15,142 l | Top dress (10-20-10) | 224 | $243 | 113 | 67 | 92 | 22 | 45 | 22 | 176 | 112 | 114 |
| | | | | | Top dress (46-0-0) | 90 | $254 | – | – | – | 41 | – | – | | | |
| Coupled (short-term) | Potato | S and L | Potato | – | Potato blend (10-10-10) | 1349 | $231 | – | – | – | 135 | 135 | 135 | 200 | 135 | 135 |
| | | | | | Side dress[2] (46-0-0) | 141 | $254 | – | – | – | 65 | – | – | | | |
| | Pot. and Dairy | S | Silage corn | 20 Mt | Side dress (46-0-0) | 140 | $254 | 185 | 46 | 166 | 65 | – | – | 250 | 46 | 166 |
| | | L | | 20,820 l | Side dress (46-0-0) | 140 | $254 | 156 | 93 | 127 | 65 | – | – | 221 | 93 | 127 |
| | | S | Hay | 11 Mt | Top dress (46-0-0) | 112 | $254 | 103 | 26 | 92 | 52 | – | – | 155 | 26 | 92 |
| | | L | Haylage | 15,142 l | Top dress (10-20-10) | 224 | $243 | 113 | 67 | 92 | 22 | 45 | 22 | 176 | 112 | 114 |
| | | | | | Top dress (46-0-0) | 90 | $254 | – | – | – | 41 | – | – | | | |
| Coupled (long-term) | Potato | S and L | Potato | – | Potato blend (10-10-10) | 359 | $231 | – | – | – | 36 | 36 | 36 | 77 | 36 | 36 |
| | | | | | Side dress[2] (46-0-0) | 90 | $254 | – | – | – | 41 | – | – | | | |
| | Pot. and Dairy | S | Silage corn | 20 Mt | Side dress (46-0-0) | 112 | $254 | 185 | 46 | 166 | 52 | – | – | 237 | 46 | 166 |
| | | L | | 20,820 l | Side dress (46-0-0) | 112 | $254 | 156 | 93 | 127 | 52 | – | – | 208 | 93 | 127 |
| | | S | Hay | 11 Mt | Top dress (46-0-0) | 112 | $254 | 103 | 26 | 92 | 52 | – | – | 155 | 26 | 92 |
| | | L | Haylage | 15,142 l | Top dress (10-20-10) | 224 | $243 | 113 | 67 | 92 | 22 | 45 | 22 | 176 | 112 | 114 |
| | | | | | Top dress (46-0-0) | 90 | $254 | – | – | – | 41 | – | – | | | |

[1] Small (S) farms used solid dairy manure (Mt ha$^{-1}$) while large (L) farms used liquid dairy manure (liters ha$^{-1}$).
[2] Separate application from at-plant fertilizer.

**Table 4.** Relative profitability of conventional and coupled potato farms.

| Profit measure | Size | Conventional[2] | --------Short-term-------- L-coupled[3] | LF-coupled[4] | --------Long-term-------- L-coupled[3] | LF-coupled[4] |
|---|---|---|---|---|---|---|
| ROVC[1] | S | $494 | $647 | $828 | $808 | $993 |
| | L | $556 | $825 | $1095 | $1011 | $1285 |
| NFI[1] | S | −$126 | $30 | $141 | $188 | $306 |
| | L | $44 | $314 | $514 | $502 | $704 |

[1] Return over variable costs (ROVC) and net farm income (NFI) in $ per hectare of owned cropland.
[2] Small (S) conventional farms grew 65 ha of potatoes and 65 ha of grain corn for a total of 130 owned crop hectares. Large (L) crop hectares were doubled.
[3] Small land-coupled raised 85 ha of potatoes and 45 ha of grain corn, while large land-coupled grew 195 ha of potatoes and 65 ha of grain corn. Owned crop hectares were the same as conventional.
[4] Land/feed-coupled owned crop hectares were the same as land-coupled. Additional crops were 40 ha of silage corn and 30 ha of hay for small and 130 ha of silage corn and 80 ha of haylage for large.

potato farms (Table 4) assuming marketable potato yields were the same. For land/feed-coupled potato farms, profits were attributed to the farm that owned the land, regardless of which farm was operating it. Revenues, costs, and returns for crop enterprise budgets were summarized previously[27,28].

In general, profitability improved going from short- to long-term coupling. The scenarios outlined in Table 4 assumed that the coupled dairy farm remained the same size. The larger coupled cropland base allowed the potato farm to grow more potatoes while maintaining the same rotation and current silage corn production by reducing the area devoted to grain corn. In the case where a 2-year potato–corn rotation was maintained, profitability increased from the expanded production of a cash crop (potato) and the reduced planting of a less lucrative rotation crop (grain corn).

For short-term land-coupled potato farms, NFI and ROVC were about $153 to $269 per hectare higher than conventional farms even assuming equal potato yields and no reductions in chemical fertilizer in the short term. Results might be different if average market prices and assumed yields for cash and rotation crops changed. The profitability of silage corn as a potato rotation crop assumed that the coupled dairy farm was close enough for manure to be applied to silage corn. Silage corn production without manure applications would lead to soil quality deterioration, may require additional chemical fertilizer, and may not be as profitable.

If land-coupled potato farms did not expand potato production and allowed the dairy farm to grow forages on their rotational cropland, profitability was still greater than conventional. NFI per hectare of owned cropland increased to −$35 and $106 for the small and large size classes (data not presented) compared to conventional NFI of −$126 and $44 per hectare (Table 4). This was from lower enterprise budget NFI per hectare for grain corn (−$454 to −$266) compared to silage corn ($127 to $268) and hay/haylage (−$45 to −$32).

Grain corn profitability may be more competitive than indicated in this study for four reasons. First, the grain corn yields assumed for this study were typical for central Maine, but were low (6.3 Mt $ha^{-1}$) compared to other areas in Maine further south. Secondly, grain corn prices may be higher. Thirdly, grain corn budgets did not account for commodity payments. Fourthly, grain corn leaves plant residues that are incorporated into the soil after harvest. While the organic matter in such residues has value, this value was not recognized in potato farm budgets.

Land/feed-coupled potato farms were more profitable than land-coupled farms due to the added revenue from growing dairy forages in addition to potatoes and grain corn (Table 4). Land/feed-coupled potato farms were even more profitable if they grew dairy forages exclusively and not grain corn, since grain corn was a less profitable enterprise than dairy forages. For short-term land/feed-coupled potato farms growing just silage corn and hay/haylage, ROVC per hectare increased to $974 for small and $1203 for large farms, while NFI per hectare increased to $336 for small and $655 for large (data not presented). This scenario assumed expansion of the coupled dairy farm to use the additional forages.

Long-term coupling improved profitability even further compared to short-term coupling (Table 4). Long-term couplers enjoyed benefits from expansion as did short-term couplers. Profitability was greater for long-term coupled farms than conventional due to decreased fertilizer costs from manure-nutrient credits taken for potatoes and silage corn and the subsequent reduction of purchased chemical fertilizer. For example, enterprise budget fertilizer costs for long-term coupled potato ($106 per hectare) were about 70% less than conventional ($348 per hectare). Similarly, enterprise budget fertilizer costs for rotation crops were less for silage corn grown on long-term coupled farms ($30 per hectare) than for both grain corn grown on conventional farms ($161 per hectare) and short-term coupled silage corn ($35 per hectare).

Some long-term coupled potato farmers believed that their potato yields had increased from improved soil quality. However, they did not have records to establish the amount of potato yield increase. Based on Maine Potato Ecosystem Project experimental field data from plots

**Table 5.** Net farm income for whole-farm budgets of coupled potato farms with yield response for potatoes ranging from −25 to 25%.

| Potato farm type | Marketable yield | | NFI ($ ha$^{-1}$)[2] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Short-term integration | | | | Long-term integration | | | |
| | | | Small | | Large | | Small | | Large | |
| | % Increase | Mt ha$^{-1}$ | Land | Land/Feed | Land | Land/Feed | Land | Land/Feed | Land | Land/Feed |
| Coupled[1] | −25% | 20.2 | −$635 | −$516 | −$442 | −$242 | −$472 | −$353 | −$255 | −$52 |
| | −20% | 21.5 | −$502 | −$385 | −$289 | −$91 | −$339 | −$220 | −$104 | **$99** |
| | −15% | 22.9 | −$371 | −$255 | −$138 | **$59** | −$208 | −**$89** | **$47** | **$250** |
| | −10% | 24.2 | −$240 | −**$124** | $12 | **$210** | −**$77** | **$42** | **$200** | **$400** |
| | −5% | 25.6 | −**$106** | **$10** | **$163** | **$363** | **$57** | **$175** | **$351** | **$554** |
| | 0% | 26.9 | **$30** | **$141** | **$314** | **$514** | **$188** | **$306** | **$502** | **$704** |
| | 5% | 28.2 | **$156** | **$272** | **$467** | **$665** | **$319** | **$437** | **$652** | **$855** |
| | 10% | 29.6 | **$289** | **$405** | **$618** | **$815** | **$452** | **$568** | **$806** | **$1006** |
| | 15% | 30.9 | **$420** | **$536** | **$768** | **$966** | **$583** | **$702** | **$956** | **$1159** |
| | 20% | 32.3 | **$551** | **$667** | **$919** | **$1119** | **$714** | **$833** | **$1107** | **$1310** |
| | 25% | 33.6 | **$684** | **$801** | **$1072** | **$1270** | **$848** | **$964** | **$1258** | **$1460** |

[1] Coupled NFI per hectare in bold face was greater than or equal to conventional NFI per acre of −$126 for small and $44 for large farms.
[2] Cropland in denominator included just owned crop hectares.

amended with manure and compost, potato yields may increase from integration because of increased soil quality, especially in dry years[15]. However, there was some evidence that increased disease pressure could suppress yields[16]. To test the impact of this potential yield variability, NFI was estimated for coupled potato farms at various marketable yields ranging between −25 and +25% from the base yield of 26.9 Mt ha$^{-1}$ (Table 5). These yield differences were assumed to be from soil quality changes from integration and not from additional fertilizer. Harvest labor, truck fuel, and storage costs were adjusted in proportion to yield changes.

Assuming marketable potato yield increased 5%, NFI for long-term coupled potato farms increased even further compared to short-term coupled by $126 to $153 per hectare. Larger sized long-term integrators were no worse off than equivalent sized conventional farms with yield losses of 15 to 20%. NFI per hectare at the conventional base yield of 26.9 Mt ha$^{-1}$ was −$126 for small and $44 for large farms. Thus a 5% increase in marketable potato yield increased NFI to about $445 to $811 per hectare more than conventional (Table 5).

## *Dairy farms*

If potato farms expanded potato production during coupling and the dairy farm did not increase herd size, benefits were minimal for land-coupled dairy farms. In the short-term, ROVC and NFI were identical to conventional farms. Long-term coupled farms had slightly greater profitability measures (Table 6) due to the small manure-nutrient credit assumed for silage corn on farms that had been integrated for more than 10 years. Silage corn enterprise budget fertilizer costs for long-term coupled dairy farms ($30 per hectare) was about 15% less than for conventional ($35 per hectare).

Land/feed-coupled dairy farms had lower profitability than conventional and land-coupled farms. Although there were no crop production expenses for land/feed-coupled dairy farms, the dairy farm did not eliminate all of the fixed costs allocated to forage crops. Profitability can be improved if prices paid to the potato farm for forages were reduced. Increased profitability from coupling in both the short term and long term may be limited for dairy farms unless they expand or unless management can be redirected from crop production to improve livestock productivity. Such potential increased profitability of the livestock enterprise was not directly reflected in budgets.

Profitability improved from short-term coupling when dairy farms expanded their herds to take advantage of the potential for more silage corn produced in the rotation. Greater profitability from livestock expansion assumed increasing returns to scale. Representative dairy farm budgets were difficult to scale up to specific herd and farm sizes. Economic benefits from livestock expansion were demonstrated by transitioning from a small to large land/feed-coupled dairy farm, where ROVC and NFI increased

**Table 6.** Relative profitability of conventional and coupled dairy farms.

| Profit measures | Size | Conventional[2] | ------- Short-term------- L-coupled[3] | LF-coupled[4] | ------- Long-term------- L-coupled[3] | LF-coupled[4] |
|---|---|---|---|---|---|---|
| ROVC[1] | S | $366 | $366 | $109 | $371 | $109 |
| | L | $788 | $788 | $462 | $793 | $462 |
| NFI[1] | S | −$605 | −$605 | −$729 | −$600 | −$729 |
| | L | −$22 | −$22 | −$269 | −$17 | −$269 |

[1] ROVC and NFI in $ $ha^{-1}$ of owned cropland. Cropland did not include pasture.
[2] Small (S) conventional dairy farms grew 40 ha of silage corn and 30 ha of hay for a total of 70 owned crop hectares. Large (L) conventional dairy farms grew 130 ha of silage corn and 80 ha of haylage for a total of 210 owned crop hectares. The 12 and 17 ha of pasture for S and L dairy farms, respectively, were not included as crop hectares.
[3] Land-coupled farms raised the same crop hectares as conventional farms.
[4] Land/feed-coupled dairy farms did not raise forages since the land/feed-coupled potato farms grew these. However, returns were calculated using the same owned crop hectares as conventional and land-coupled farms.

by $96 per hectare and $336 per hectare, respectively, compared to both the conventional and short-term land-coupled small dairy farm (Table 6). In this demonstration, the silage corn grown by the coupled potato farm increased from 40 to 104 ha to take advantage of all rotational cropland available from coupling. This scenario assumed the expanding dairy farm purchased the equivalent of an additional 25 ha of silage corn and 51 ha of haylage for increased feed needs beyond the increase provided by the coupling arrangement.

Improved profitability may be underestimated for coupled dairy farms since silage corn yields were assumed to be the same as conventional. Higher silage corn yields from rotating out of continuous corn may be expected and would improve profitability by allowing for herd expansion. Also, it is possible for both potato and dairy farms to benefit from coupling if dairy farms expand herd size while the potato farm increases potato acreage.

### *Potato and dairy systems*

Coupled and conventional comparisons previously focused on the potato or dairy side of the coupled relationship. Conventional and coupled budgets were also compared as agricultural systems with potato and dairy components (Table 7). Acreages, revenues, and costs for potato and dairy farms were aggregated. To compare segregated to integrated systems, conventional systems were artificially combined.

For short-term integrated systems, ROVC and NFI were higher for coupled compared to conventional due to greater profitability of coupled potato farms from increased potato acreage. For long-term integrated systems, profitability was greater than conventional due to reduced fertilizer use for both potatoes and silage corn in coupled systems. Differences in ownership and operating costs for land-coupled and land/feed-coupled cases were due to different machinery, equipment storages, and maintenance costs for potato compared to dairy farms. Thus profitability for these coupled systems was similar, though not identical when comparing the same size and integration history.

Profitability of coupled systems in central Maine where the potato farm expanded and the dairy farm remained the same size was itemized into four separate components: (1) increased potato acreage, (2) manure nutrient credits, (3) shifting from land- to land/feed-coupled, and (4) a 5% assumed increase in potato yields. On average, gains in NFI were $124 per hectare from expansion of potato acreage during short-term coupling. In the long term if manure nutrient credits were taken, average gains were an additional $106 per hectare. Shifting from land- to land/feed-coupled provided relatively minimal system gains ($15 per hectare). If potato yields increased by 5%, system NFI increased on average by an additional $208 per hectare (Table 8).

## Conclusions

Integrating crops and livestock through inter-farm coupling increased profitability for both potato and dairy farms. Benefits from coupling potato and dairy farms were less direct than originally expected because farmers did not capture all of the potential gains during early transition years. For example, short-term couplers did not take manure-nutrient credits for potatoes and silage corn, while long-term couplers took these credits. Surveyed farmers were hesitant to expose themselves to the risk of taking manure-nutrient credits for uncertain yield increases in high-value crops, such as potatoes, especially when chemical fertilizer was relatively inexpensive. These risks are greater in the short term when organic matter levels are low from less manure applications.

Analyses of representative budgets suggest that potato and dairy systems coupled for only 2 years (short-term) had greater profitability than conventional non-coupled systems even if marketable potato yields were the same as conventional. Profitability increased in the short term since land base expanded from coupling. Potato farms were able to grow more potatoes, a more profitable cash crop, and less grain corn, a less profitable rotation crop, while keeping the same rotation sequence. This was possible because silage

**Table 7.** Whole-farm budget summary for conventional and coupled farm systems.

| System size | Coup. history | System type | Crop (ha) | | | | System budget[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Potato | Grain corn | Silage corn | Hay/Haylage | Total | Rev. | Oper. costs | Own. costs | ROVC | NFI |
| S | None | Conv. | 65 | 65 | 40 | 30 | 200 | $2389 | $1900 | $783 | $489 | −$294 |
| | ST | L-Coup. | 85 | 45 | 40 | 30 | 200 | $2735 | $2145 | $783 | $590 | −$193 |
| | | LF-Coup. | 85 | 45 | 40 | 30 | 200 | $3002 | $2385 | $781 | $617 | −$164 |
| | LT | L-Coup. | 85 | 45 | 40 | 30 | 200 | $2735 | $2039 | $783 | $696 | −$87 |
| | | LF-Coup. | 85 | 45 | 40 | 30 | 200 | $3002 | $2278 | $781 | $724 | −$57 |
| L | None | Conv. | 130 | 130 | 130 | 80 | 470 | $2688 | $1989 | $684 | $699 | $15 |
| | ST | L-Coup. | 195 | 65 | 130 | 80 | 470 | $3165 | $2318 | $684 | $847 | $163 |
| | | LF-Coup. | 195 | 65 | 130 | 80 | 470 | $3504 | $2651 | $690 | $853 | $163 |
| | LT | L-Coup. | 195 | 65 | 130 | 80 | 470 | $3165 | $2212 | $684 | $953 | $269 |
| | | LF-Coup. | 195 | 65 | 130 | 80 | 470 | $3504 | $2545 | $690 | $959 | $269 |

[1] Revenue, costs, and returns are in $ ha$^{-1}$ of total potato and dairy farm cropland, not including pasture.

corn was added as a rotation crop during coupling with the dairy farm.

Potato and dairy systems coupled for more than 10 years (long-term) had more favorable profitability than short-term coupled systems as farmers maintained an integrated agricultural system over many years. Due to greater manure-nutrient credits taken in the long term for potatoes and silage corn, long-term coupled potato farms could have withstood 10–20% marketable yield losses and still have been as profitable as conventional farms. The scenario improved even more if potato yields increased following several years of manure application, as suggested by long-term rotation plot studies in Maine.

Cooperating coupled farms mentioned that integration provided more land base for dairy farm expansion and greater opportunities for disposal of livestock waste. Thus, integrating crops and livestock may be encouraged where livestock farms have expanded or desire to expand and crop farms are close enough to couple. Land/feed-coupled dairy farms can focus solely on managing livestock since the coupled potato farm manages forage. Land exchanges may reduce land rental costs. Some coupled farms stated that their managerial skills improved from interaction with another specialized producer. Shared equipment and labor were other cited benefits. In addition to economic benefits, advantages of integrated systems such as improved soil quality may be more difficult to quantify.

Our research demonstrated both short- and long-term economic benefits for coupled integration in central Maine. However, integration is not extensively practiced by potato and dairy farms in this state. Only about 1.4% of potato farms, 2.5% of dairy farms, and 5.3% of potato and dairy farm cropland are integrated. Challenges to integrating potato and dairy systems include: (1) distance and transaction costs between potential couplers, (2) establishing and maintaining successful coupled relationships, (3) management of inter-farm coupling and other crops, (4) dairy relocation risks, (5) the terms of processing potato contracts, and (6) structural factors such as farm specialization and consolidation in addition to infrastructure and markets.

Even if coupling is more profitable in both the short term and long term than non-integrated systems, unless farmers are willing to relocate, it still requires farms to be in close proximity. Coupling between cooperating farms usually occurs within 10 miles of the dairy farm. The current potential for integration may be limited given the spatial separation of the two industries in Maine (Fig. 2). Our analysis assumed equal manure and forage transport costs for coupled and conventional farms. Greater distance between couplers would increase such transaction costs as well as the risk of inadequate forage quality for dairy farms. In addition to a proximity requirement, coupled sets of farms need to be of similar scale to further reduce the transaction costs of the relationship. For example, a 500-cow dairy farm would have more transaction costs associated with integrating with 50 ten-acre potato farms

**Table 8.** System profitability increases of component parts of coupling in central Maine (NFI in \$ $ha^{-1}$ of potato and dairy farm cropland).

| Coupling components | Farm size | | | Percentage of total | |
|---|---|---|---|---|---|
| | Small | Large | Average | w/o Yield increase (%) | w/ Yield increase (%) |
| Crop acreage changes | \$101 | \$148 | \$124 | 51 | 28 |
| Manure nutrient credits | \$106 | \$106 | \$106 | 43 | 23 |
| Coupling arrangement[1] | \$30 | \$0 | \$15 | 6 | 3 |
| Potato yield increase | \$183 | \$232 | \$208 | | 46 |

[1] Shifting from land- to land/feed-coupled.

rather than one 500-acre potato farm. Likewise, a potato farm would have more transaction costs from integrating with multiple dairy farms.

Farmers engaged in inter-farm coupling need to have adequate working relationships. Most coupling arrangements were verbal and not formally written down on paper. Current potato and dairy couplers in Maine stressed that worrying about which producer was making out better in the short term was not the basis of a successful relationship. Instead, cooperating producers emphasized faith and trust that the relationship would benefit both crop and livestock farms in the long term. Many farmers may not be able to do this. Despite the prevalence of inter-farm coupling in central Maine, many potato and dairy farmers in this part of the state were not integrated. These farmers may not be willing to trust and deal with another farmer in such a relationship even if there are short- and long-term economic benefits.

The added management time needed to coordinate coupling with others may not be appealing to certain farmers. Land-coupled management is the most simple, where potato and dairy farmers decide where potatoes and forage rotations are grown. Land/feed coupling is more complex since the potato farmer needs to adequately manage forage in addition to potatoes. Cooperating dairy farmers that were considering coupling in this manner stressed that the dairy farmer needed to work closely with the potato farmer during early transition years to ensure adequate forage quality.

Other challenges to integrating crop and livestock systems are dairy relocation risks. Two cooperating dairy farmers considered relocating to Aroostook county to start up new dairy operations under a land/feed-coupled arrangement. Under this hypothetical coupling arrangement, the dairy farmer would not purchase any cropland, instead using only enough land for structures and for manure and feed storages. Dairy farmers would be entirely dependent on the potato farmers they are coupled with for forage. If for some reason the coupled relationship does not work out, the dairy farmer may find it challenging to purchase or rent enough nearby cropland to raise forage.

The terms of processing potato contracts may limit integration. Potato farms under contract may not be able to expand acreage and realize short-term benefits of coupling. Also, diseases such as powdery scab that are associated with greater soil moisture from applied manure may reduce potato quality, resulting in contract penalties or even rejection of shipments by processors. For processing growers raising proprietary varieties, it may be easier to grow and sell potatoes with reasonable scab resistance. For seed potato farmers selling a wide range of cultivars, this may not be the case.

Structural factors such as specialization and spatial consolidation of crop and livestock industries in addition to infrastructure and markets may further challenge integration. For example, farms in Aroostook county have specialized in potato production and no longer have both potato and dairy enterprises on the same farm. Aroostook has also seen a decline in its dairy industry, which used to be one of the top milk-producing counties in Maine. The number of dairy farms and service firms such as fluid milk processors, agricultural supply companies, and breeders have also decreased. Widespread future coupling in Aroostook would require not only an increase in livestock farms, but accompanying infrastructure and markets. In addition, relocation of dairy farms to Aroostook county may be further challenged by lack of financing for start-up costs.

Short- and long-term benefits and challenges for coupling crops and livestock in central Maine may be applicable to other areas where agricultural specialization has occurred. In areas such as the Midwest, which have less of a competitive advantage in forage relative to grain corn, economic benefits from coupling may be limited. As these results suggest, distance and transaction costs between potential couplers, relationships with other farmers, management, and specialization and spatial separation of crop and livestock industries are key factors that make integration challenging, despite potential economic benefits. Additionally, certain farmers may choose to remain or become on-farm integrated rather than couple with other farms. Thus, the profitability of on-farm integration should be analyzed, in particular cases where mixed vegetables and concentrated livestock feed crops such as grain corn, soybeans, and barley are raised.

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# Book Review

**Gardening for the Earth and Soul.** By Heather Dean and Tom Benevento. 2004. Brethren Press, Elgin, IL. 180 p. $18.99, ISBN: 0–87178–053–4.

*Gardening for the Earth and Soul* is a book that provides both inspiration and practical information for the gardening novice and expert alike. In fact, the book is much like a garden itself. The gentle, earthy writing, the peaceful and joyous artwork, the potpourri of tidbits, stories, recipes, suggestions for children's activities, poems, and how-to information reminded me of a walk through a garden—so many smells and sights, new and familiar, so much beauty and life. At the same time, if the reader needs to stop walking and sit quietly to study more deeply a particular topic covered in this book, he may find himself wanting and needing more.

The book covers a very wide range of topics from the basics of composting, soil preparation, seed saving, transplanting and cultivation tips for the major food crops to pest control, season extension, food storage, lawn care, forest gardening, and community gardening (to name a few!). I found this range to be both enjoyable and worrisome. It is certainly fun to read this book as the subject matter changes regularly and sometimes unpredictably. Like a winding garden path, you never know what you'll encounter around the next bend. The disadvantage of this style is that it can be a little difficult to find particular information. In addition, I worry that this may not be a book for the absolute novice who has high hopes for a first garden. While many topics are covered, generally each topic is covered fairly superficially and there may not be enough information to equip the true novice. While the author lists some additional, more comprehensive resources, often the list is quite limited and does not include some well-respected and useful books. This may be due in part to the author's background and emphasis on permaculture techniques. However, the lack of hand-holding could be ideal for more experienced gardeners looking for new ideas, inspirations and techniques.

This book excels as a reminder to all of us of our connection to the soil, of our role as caretakers, and of a simpler way of being. Gaining the skills outlined in this book can be incredibly rewarding—the reader can gain a deeper, experiential understanding of the natural world upon which we all depend, and learn how to interact with the natural world in mutually beneficial, rather than harmful, ways. In addition, the book excels at inspiring gardeners to include children and other community members in their gardening activities. Gardening can often be a solo or familial activity, but has such a tremendous potential to positively affect many lives outside our comfortable boundaries.

The author promotes a permaculture method of soil preparation that requires digging the soil and then adding wetted newspaper and $1\frac{1}{2}$ to 2 feet of straw. This is a time-tested, successful method, but is it sustainable? When we add straw, we are taking the nutrients (and future organic matter) from another soil in order to enrich our garden's soil, in effect robbing Peter to pay Paul. Since soil can only produce about a 1-inch layer of straw for itself each year, this method requires that you remove the straw (and its nutrients and organic matter potential) from an area of soil that is 18–24 times the area of your garden! While you may only need to do that once, it is in the spirit of this book to consider the environmental ramifications of the gardening methods you use.

*Gardening for the Earth and Soil* is an enriching book that covers a wide range of topics. For gardeners with some experience looking for new inspiration and a reminder to simplify and reconnect with the soil, the Earth and the wonder that is a garden, this book is a garden path you will enjoy experiencing.

*John Beeby, Molecular Diagnostic Lab, Cornell University, Kindred Spirits Farm, 344 Halseyville Road, Ithaca, NY 14850-9232, USA.*
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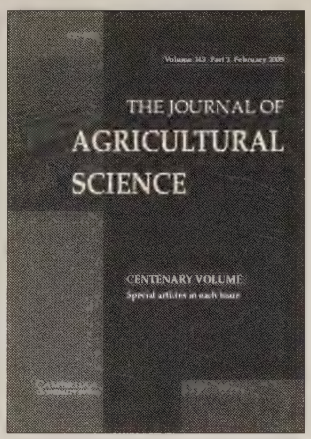


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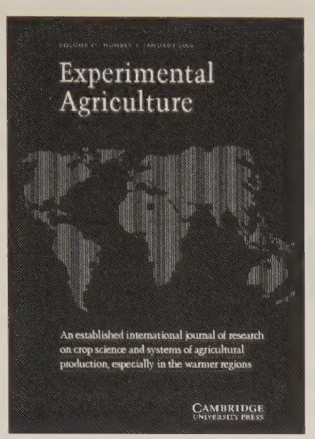
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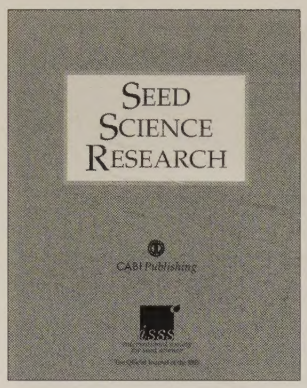


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2. Brink, R.H. Jr, Dubach, P., and Lynch, D.I., 1960. Measurement of carbohydrates in soil hydrolyzates with anthrone. Soil Science 89:157–166.
3. Greenland, D.J., and Szabolcs, I., (eds). 1994. Soil Resilience and Sustainable Land Use. CAB International, Wallingford, UK.
4. Arshad, M.A., and Coen, G.M., 1992. Characterization of soil quality: Physical and chemical criteria. American Journal of Alternative Agriculture 7:25–31.
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